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NASA CONTRACTOR REPORT

NASA CR-119

NASA CR-119

FACILITY FORM 602

N64 32830
(ACCESSION NUMBER)

(THRU)

123
(PAGES)

1
(CODE)

(NASA CR OR TMX OR AD NUMBER)

04
(CATEGORY)

THE EFFECT OF RU
ON THE DYNAMIC
SUPERSONIC TRANS

by C. C. Tung, J. Penzie

Prepared under Grant No. NsG-348 *by*
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THE EFFECT OF RUNWAY UNEVENNESS ON THE DYNAMIC RESPONSE OF SUPERSONIC TRANSPORTS

By C. C. Tung, J. Penzien, and R. Horonjeff

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UNIVERSITY OF CALIFORNIA
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce,
Washington, D.C. 20230 -- Price $2.75

ABSTRACT

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An analysis has been developed for determining the dynamic response of airplanes to runway unevenness during take-off or landing and has been programmed for numerical solution on an IBM 7090 digital computer. This analysis permits the inclusion of the landing gear non-linear characteristics and the flexural mode characteristics of the free-free airframe. To test the practicability of the analysis the dynamic response of the Boeing 733-94 (SCAT) supersonic airplane and the Boeing 707 airplane on Runway 12, Langley Field, and on Runway 28R, San Francisco International Airport was determined. The numerical results are presented in graphical form and their significant characteristics are discussed.

In addition statistical methods of analysis of certain non-linear systems which may be applicable in determining the dynamic response of airplanes to runway unevenness of the stationary type are also included in this report.

Author

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NOMENCLATURE

A_a	pneumatic cross sectional area of landing gear system
A_h	hydraulic area of landing gear system
A_n	net orifice area of landing gear system
C_d	coefficient of discharge in landing gear system
c	damping coefficient of two-mass system (see Fig. 27)
c_j	damping coefficients in each of the flexural modes
c_{ij}	elements of the damping matrix in Eq. (20)
D	a function of strut stroke associated with damping force in landing gear system
e	error function
F_d	nonlinear damping force in landing gear system
F_i	Coulomb friction force in landing gear system
F_i'	limiting Coulomb friction force in landing gear system
$F_n(t)$	quantity defined by Eq. (102)
F_s	nonlinear spring force of landing gear system
$\bar{F}_s$	static value of nonlinear spring force in landing gear system
F_t	interacting force between runway surface and wheel
$f(t)$	forcing function
G	quantity associated with damping force in landing gear system
$G_n(t)$	quantity defined by Eq. (109)
g	gravitational acceleration
$g(x,\dot{x})$	a nonlinear function
$h(s)$	runway elevation
$h(t)$	unit impulse response
J	rigid body rotary moment of inertia about the center of gravity of airplane
K_{ij}	elements of the stiffness matrix in Eq. (20)

K_t	stiffness of tire springs
k_1, k_2	stiffness of springs (see Fig. 27)
k_{1i}, k_{2i}	coefficients of piece-wise linearized spring force of landing gear system
L_1, L_2	aerodynamic lift forces at the wings and the canard, respectively
$L_{11}, L_{12}, L_{21}, L_{22}$	coefficients defined by Eq. (3)
L	horizontal distance between the position of the pilot and the center of gravity of airplane
M_1, M_2	masses of the main and nose tire-landing gear systems, respectively
M_3, M_4	generalized masses of rigid body translational and rotational modes, respectively
M_j	generalized mass of flexural mode; j=5,6----N
m_1, m_2	masses of two-mass systems (see Fig. 27)
N	total number of degrees of freedom of the system
N_1	number of flexural modes considered
O_1, O_2	points of attachment of the main and nose landing gears, respectively
P_3, P_4	generalized forcing functions of rigid body translational and rotational modes, respectively
P_j	generalized forcing function of flexural mode; j=5,6----N
p	air density
$p(x)$	probability density function
p_{ao}	air pressure in upper chamber for fully extended struts of landing gear system
Q	interacting force between airframe and landing gear system
$\bar{Q}$	static value of Q
$R(\tau)$	autocorrelation function
R_n	quantity defined by Eq. (101)

S_f	power spectral density function of forcing function
S_1, S_2	plan form areas of the wings and canard, respectively
s	horizontal distance along runway
s_1, s_2	strut strokes of the main and nose landing gear systems, respectively
t	time
U_1, U_2	displacements of the points of attachment of the main and nose landing gears on the airframe, respectively
V_0	chamber air volume for fully extended strut of landing gear system
v	speed of airplane
W	gross weight of airplane
W_1, W_2	weights of the main and nose landing gear systems, respectively
w	total vertical displacement of any point on the airframe
X_1, X_2	displacements of main and nose wheel masses, respectively
$\bar{X}_1, \bar{X}_2$	static displacements of main and nose wheel masses, respectively
X_3, X_4	generalized coordinates of the rigid body translational and rotational modes, respectively
X_j	generalized coordinate of flexural mode; j=5,6----N
x	reference axis; displacement
x_0	solution of Eq. (46) when $\kappa=0$
x_i	i^{th} perturbation; i^{th} element of vector $\left\{x\right\}$
y	reference axis
y_i	i^{th} element of vector $\left\{y\right\}$
z_i	i^{th} element of vector $\left\{z\right\}$
α	eigenvalue
$\alpha_{11}, \alpha_{12}, \alpha_{21}, \alpha_{22}$	aerodynamic lift coefficients
β	damping coefficient per unit mass

β_{eq}	equivalent linear damping coefficient per unit mass
γ	damping coefficient
Δt	time increment used in numerical procedure
$\bar{\Delta}_1, \bar{\Delta}_2$	static shortening of main and nose landing gears, respectively
$\Delta(s)$	runway elevation (see Fig. 27)
δ_{ij}	Kronecker Delta function
$\delta(t)$	Dirac Delta function
ϵ	mass ratio defined by Eq. (128)
ζ	quantity defined by Eq. (128)
η	quantity defined by Eq. (128)
θ_1, θ_2	angles of attack at the wings and the canard, respectively
λ	structural damping coefficient
κ	perturbation parameter
ξ_n	generalized coordinate of multi-degree of freedom system
ρ	mass density of hydraulic fluid in landing gear system
σ	standard deviation
$\phi^3(x,y), \phi^4(x,y)$	mode shapes of rigid body translation and rotation respectively
$\phi^j(x,y)$	flexural mode shapes; j=5,6----N
ϕ_1^j, ϕ_2^j	values of mode shapes at points of attachment of the main and nose landing gears on the airframe, respectively; j=5,6----N
ϕ_3^j, ϕ_4^j	values of mode shapes at the aerodynamic centers on the wings and the canard, respectively; j=5,6----N
ϕ_5^j	value of mode shape at pilot location; j=5,6----N
$\psi(\Delta s)$	autocorrelation function of runway profile
$\psi(0)$	mean square value of runway profile
ω_d	frequency of damped system

ω_0	frequency of undamped system
ω_1, ω_2	quantities defined by Eq. (128)
ω_j	flexural modal frequency
ω_{eq}^2	equivalent linear stiffness coefficient per unit mass
$\{a\}$	vector defined by Eq. (25)
$\{b\}$	vector defined by Eq. (25)
$[C]$	damping matrix of the linearized equations of motion of airplane
$[c]$	damping matrix of multi-degree of freedom system
$\{F(t)\}$	vector defined by Eq. (79)
$\{f(t)\}$	forcing function vector
$\{g\}$	a nonlinear function
$[I]$	identity matrix
$[K]$	stiffness matrix of the linearized equations of motion of airplane; matrix defined by Eq. (81)
$[k]$	stiffness matrix of multi-degree of freedom system
$[M]$	mass matrix of the linearized equations of motion of airplane
$[m]$	mass matrix of multi-degree of freedom system
$\{q\}$	vector defined by Eq. (78)
$[R]$	matrix defined by Eq. (80)
$\{R\}$	forcing function vector of the linearized equations of motion of airplane

NOMENCLATURE (Cont'd)

$\left[T\right]$	matrix defined by Eq. (24)
$\left[U\right]$	matrix defined by Eq. (86)
$\left\{X\right\}$	displacement vector of the linearized equations of motion of airplane
$\left\{x\right\}$	solution of Eq. (71) when $\kappa=0$
$\left\{y\right\}$	first perturbation vector
$\left\{z\right\}$	displacement vector
$\left\{\Phi\right\}$	eigenvector
$\left\{\phi\right\}$	quantity associated with eigenvector

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ACKNOWLEDGMENT

The authors are grateful to the organizations and individuals who furnished data and offered helpful suggestions for this research, particularly to Messrs. H. L. Runyan, U. T. Joyner, S. A. Batterson, W. J. Alford, and C. Driver of the Langley Research Center, National Aeronautics and Space Administration; Messers. G. Newell and R. Skoog of the Boeing Company; and Messrs. W. Stauffer, J. Wignot, and F. Hoblit of the Lockheed-California Company.

Thanks are also extended to the Public Utilities Commission, City and County of San Francisco, for furnishing the profile data for Runway 28R, San Francisco International Airport, and to Messrs. R. N. Bingman and B. Groomes of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, for furnishing the profile data for several Air Force runways.

I INTRODUCTION

The effects of runway unevenness on the design and operation of airplanes has been subject to scrutiny for a number of years. The National Aeronautics and Space Administration recognized this problem at its start and has devoted considerable attention to it.*

Although in the literature the term "runway roughness" is used, it is preferred herein to refer to this characteristic as "runway unevenness" since it is the longer wave length variations in the longitudinal profile of the order of 50 to 100 feet that are significant and not the shorter wave length variations. Thus, changes in runway profiles due to intersections, unequal settlements, etc. could possibly result in unevenness detrimental to airplane operation. It was the primary objective of this investigation to study the dynamic response of airplanes resulting from this type of unevenness. To carry out this objective an analytical method was developed which would yield (1) the dynamic loads induced in the airframe and landing gear systems, and (2) the vertical accelerations experienced at the pilot's position, as the airplane accelerates or decelerates on the runway during take-off or landing. It is important to have this information, particularly for the supersonic transport since it must be designed to operate at airports now being served by large supersonic jets.

Two general methods of analysis have been considered in this investigation, i.e. deterministic and statistical (power spectral). The statistical approach is easily applied if the runway unevenness is of the stationary type and if the airplane has linear response characteristics. However, since the response characteristics of the airplane are non-linear, this approach has been difficult to apply regardless of the type of unevenness considered. In any case this approach does not apply when considering such discrete conditions as the unevenness present at most runway intersections. To properly consider these conditions one must use a deterministic approach.

*See bibliography

The deterministic approach described in this report is a numerical step-by-step approach which makes use of the digital computer. This method of analysis was selected because of the highly non-linear characteristics of the landing gear systems. The landing gear spring is highly non-linear over large displacements and the damping present usually consists of both Coulomb damping and non-linear viscous damping. To properly include these non-linear effects, one must solve the non-linear differential equations of motion.

Thus the deterministic analysis, in brief, consists of (1) setting up the coupled differential equations of motion of the airplane which govern the response, (2) determining the forcing functions to be introduced into these equations which are directly related to the profile of the runway and to the time history of the airplane velocity during take-off or landing, and (3) solving these differential equations of motion numerically on a digital computer. Ten coupled differential equations of motion were solved in the investigation reported herein. This number of equations provided for two rigid body modes (i.e. vertical translation and pitching of the airplane), six symmetrical flexible modes of the free-free airframe, and an additional degree of freedom which is present in each of the two landing gear systems. These ten equations were put in difference form and coded for solution on the IBM 7090 computer; thus, yielding numerical solutions for the following parameters at any point along the runway as the airplane accelerates or decelerates during take-off or landing:

1. Vertical displacements of nose-gear and main-gear wheels
2. Forces on the runway pavement exerted by the nose-gear and main- gear
3. Vertical displacement at pilot's position
4. Vertical acceleration at pilot's position
5. Vertical translation of the airplane center of gravity

6. Pitching (rotation) of the airplane about the center of gravity

7. Generalized coordinates of each flexible mode.

In order to test the validity of the deterministic approach, Boeing and Lockheed furnished the structural characteristics for their supersonic transport design (SCAT) developed for the National Aeronautics and Space Administration. In addition, Boeing furnished similar information for the Boeing 707 airplane. Because of the limited time available for this study only the Boeing data (707 and 733-94) were used in the analysis.

The dynamic response of the subsonic 707 and the supersonic 733-94 airplanes was determined using Runway 12 at Langley Field, Virginia, and Runway 21R, San Francisco International Airport, as input profile data. Using the Langley Field data, the response of each airplane was determined for a constant velocity of 100 ft/sec. (59 knots). Using the San Francisco International Airport data, the 707 airplane was accelerated from zero velocity at an assumed rate of 5.36 ft/sec^2 and the 733-94 airplane was accelerated from zero velocity at an assumed rate of 6.0 ft/sec^2.

Although the statistical or power spectral approach cannot properly reflect the effect of discrete runway unevenness such as occur at runway intersections or at points of excessive settlement, it may be very useful when considering fatigue effects within the landing gear systems. The application of this approach to non-linear systems is normally very difficult. However, an attempt has been made in this report to show how this approach might be applied to non-linear systems. Further investigation is needed to verify the validity of this method.

II DETERMINISTIC APPROACH

General

As previously mentioned a rational design of an airplane operating on runways should take into consideration both the effects of discrete runway bumps as well as the effects of the more stationary type of runway unevenness. A single discrete runway bump of relatively long wave length (50 - 100 ft) could possibly create large dynamic loads and vertical accelerations at the location of the pilot. Because of the discrete character of this problem, it is necessary that time histories of the transient dynamic response be determined using airplanes having known structural characteristics and using various types of bumps as the excitation. Since this problem is a deterministic one, it can be solved rapidly using a digital computer and the numerical procedures set forth in the following sections of this report.

Idealization of Aircraft

Fig. 1 shows diagrammatically the idealized representation of the airframe-landing gear systems used in this investigation. In the analysis it is assumed that the profile elevation of the runway, as measured from an arbitrary horizontal datum plane and designated by h is constant across the width of the runway; thus, the dynamic response is symmetrical about the longitudinal axis of the aircraft. The quantities W and J as shown in Fig. 1 represent respectively the total weight of the airplane and its rotary moment of inertia with respect to a transverse axis through its center of gravity (C.G.). The airframe, instead of being considered as a rigid body, is treated as a flexible system.

For smaller aircraft, a rigid body representation of the airframe is usually sufficient; however, for large supersonic transports the landing gear attachment points experience such large vertical displacements relative to the nodal points of the flexible airframe that the interaction effects between the deformations of the airframe and the landing gear systems must be taken into account.

The landing gear systems are considered to be the standard conventional oleo-pneumatic shock strut type (19). The dynamic analysis as used in this investigation therefore takes into account the forces due to the hydraulic resistance of the orifice, the forces due to air compression, and the forces due to internal friction in the shock strut. These forces can be represented as shown in Fig. 1 by a nonlinear dashpot, nonlinear spring and a Coulomb frictional device respectively. The tire force-deflection relationship is essentially linear so that a linear spring can be used to represent it. Damping or hysteresis effects in the tire are sufficiently small so that they can be neglected. Each of the two lower masses, as represented by weights W1 and W2 in Fig. 1 represent the wheel masses plus an effective mass of the landing gear system in each case.

Equations of Motion of the Free-Free Airframe

The free-free airframe is considered as a two dimensional elastic system as illustrated in Fig. 2a. The forces acting on the airframe consist of the concentrated landing gear forces Q1 and Q2 and the aerodynamic lifts L1 and L2 passing through their respective aerodynamic centers $(a.c.)_1$ and $(a.c.)_2$. The aerodynamic forces as presented here represent those forces on a delta wing type aircraft which has a forward canard lifting surface. These aerodynamic lift forces may be expressed as follows:

$$L_1 = (L_{11} + L_{12}\theta_1)\, v^2 \tag{1}$$

$$L_2 = (L_{21} + L_{22}\theta_2)\, v^2 \tag{2}$$

where

$$\begin{aligned} L_{11} &= \alpha_{11}\left(\tfrac{1}{2}pS_1\right) \\ L_{12} &= \alpha_{12}\left(\tfrac{180}{\pi}\right)\left(\tfrac{1}{2}pS_1\right) \\ L_{21} &= \alpha_{21}\left(\tfrac{1}{2}pS_2\right) \\ L_{22} &= \alpha_{22}\left(\tfrac{180}{\pi}\right)\left(\tfrac{1}{2}pS_2\right) \end{aligned} \tag{3}$$

and where

v is the speed of the airplane,

θ_1, θ_2 are the angles of attack on the wings and the canard, respectively,

α_{11}, α_{12}, α_{21}, α_{22} are the aerodynamic lift coefficients,

p is the density of the air,

S_1, S_2 are the plan form areas of the wings and the canard, respectively.

The equations of motion for the airframe are formulated in terms of the normal flexible modes of the free, unrestrained airframe and the two rigid body modes, namely, vertical translation and pitch. In the analysis only a finite number N_1 of the flexible normal modes need be considered.

A set of reference axes (x, y) as shown in Fig. 2 with the origin located at the center of gravity of the airframe is used. The total vertical displacement $w(x,y,t)$ of any point on the airframe can be expressed in terms of the rigid body translation, the pitch or rotation of the x axis about the y axis, and the elastic deformation of the airframe with respect to the moving xy axis. Thus the total vertical displacement of any point on the airframe from any horizontal reference plane can be expressed by the equation:

$$w(x,y,t) = \sum_{j=3}^{N} \phi^{j}(x,y)\, X_j(t) \; ; \; N = N_1 + 4 \tag{4}$$

where the translation and rotation of the x axis are represented by rigid body modes of zero frequencies and denoted by

$$\begin{aligned} \phi^{3}(x,y) &= 1 & \omega_3 &= 0 \\ \phi^{4}(x,y) &= -X & \omega_4 &= 0 \end{aligned} \tag{5}$$

The terms $X_3(t)$ and $X_4(t)$ represent the generalized or normal coordinates, respectively, of these rigid body modes. The elastic displacements of the airframe with respect to the xy axes are represented by a superposition of the flexible normal modes which have finite frequencies. The shapes and corresponding frequencies of these modes are denoted by:

$$\begin{array}{ll} \phi^{5}(x,y) & \omega_5 \\ \phi^{6}(x,y) & \omega_6 \\ \vdots & \vdots \\ \phi^{N}(x,y) & \omega_N \end{array} \tag{6}$$

and their respective normal coordinates are represented by $X_5(t)$, $X_6(t)$- - - - $X_N(t)$.

It is to be noted that $X_1(t)$ and $X_2(t)$ are reserved for the vertical displacements of the unsprung masses M_1 and M_2 respectively.

The equations of motion of the elastic airframe therefore consist of the following:

$$\frac{W}{g}\ddot{X}_3 \equiv M_3\ddot{X}_3 = P_3(t) \tag{7}$$

$$J\,\ddot{X}_4 \equiv M_4\ddot{X}_4 = P_4(t) \tag{8}$$

$$M_j\ddot{X}_j + 2\lambda\, M_j\omega_j\dot{X}_j + M_j\omega_j^{2}X_j = P_j(t); \quad j = 5,6,\ldots N \tag{9}$$

In Eqs. (7), (8), and (9) and in the following, dots represent time derivatives, M_j is the generalized mass of the jth mode and λ is a damping coefficient which is assumed to be the same for each flexible mode. $P_j(t)$ is the generalized forcing function of the jth mode and is given as follows:

$$P_j(t) = -(Q_1 - \bar{Q}_1)\,\phi_1^j - (Q_2 - \bar{Q}_2)\,\phi_2^j - L_1\phi_3^j - L_2\phi_4^j \tag{10}$$

Here Q_1 and Q_2 represent the total interacting forces between the airframe and the main and nose landing gears, respectively. $\bar{Q}_1$ and $\bar{Q}_2$ represent corresponding static value when v=0. The notation ϕ_i^j denotes the jth mode shape; the subscripts i of ϕ_i^j indicate the location on the airframe where the ϕ^j values are referred to. Thus, i=1 and i=2 refer to the points O_1 and O_2 on Fig. 2a respectively; i=3 and i=4 refer to the aerodynamic centers $(a.c.)_1$ and $(a.c.)_2$ respectively.

Equations of Motion of the Unsprung Masses

Consider the ith landing gear system as shown in Fig. 2b. X_i represents the displacement of the mass M_i and U_i represents the vertical displacement of point O_i; both X_i and O_i are measured from their respective equilibrium positions at v=0. U_i can be expressed in terms of the normal coordinates X_i of the airframe as follows:

$$U_i = \sum_{j=3}^{N} X_j(t)\,\phi_i^j \tag{11}$$

The interacting force between the ground and the tires is F_{ti} and is expressed as

$$F_{ti} = K_{ti}\,(\bar{X}_i + X_i + h_i) \tag{12}$$

where K_{ti} is the stiffness of the tire spring and $\bar{X}_i$ is the static downward displacement of the mass M_i. To take into account the fact that the landing gear tires might leave the runway surface at certain instants of time and that the tire spring forces can not take on negative values, K_{ti} should be assigned a zero value whenever the quantity in the bracket to Eq.(12) becomes smaller than zero.

In the suspension system the nonlinear spring force (pneumatic force) is given by the relation

$$F_{si} = P_{aoi}A_{ai}\left(\frac{V_{oi}}{V_{oi} - A_{ai}s_i}\right) \tag{13}$$

where

p_{aoi} is the air pressure in the upper chamber for fully extended strut,

A_{ai} is the cross sectional pneumatic area,

V_{oi} is the chamber air volume for fully extended strut, and

$s_i = U_i - X_i + \bar{\Delta}_i$ is the strut stroke.

The term $\bar{\Delta}_i$ represents the static shortening of the nonlinear spring. The damping force (hydraulic force) in the suspension system is denoted by F_{di} and is expressed as

$$F_{di} = \frac{\dot{s}_i}{|\dot{s}_i|} \frac{\rho_i A_{hi}^3}{2(C_{di}(s_i))A_{ni}^2} \dot{s}_i^2 \tag{14}$$

where

ρ_i is the mass density of hydraulic fluid,

A_{ni} is the net orifice area,

A_{hi} is the hydraulic area,

C_{di} is the coefficient of discharge.

The factor $\frac{\dot{s}_i}{|\dot{s}_i|}$ is simply introduced to indicate the proper sign of the hydraulic resistance. For brevity, the damping force is rewritten in the following form

$$F_{di} = \frac{\dot{s}_i}{|\dot{s}_i|} D_i(s_i) \dot{s}_i^2 \tag{15}$$

The internal frictional force in the suspension system depends on the magnitude of the forces on the axle, the spacing of the bearings and the coefficient of friction between the bearings and the cylinder walls and results in a rather complicated expression (19). In this analysis it is assumed that the frictional force F_i developed in the suspension system varies between $\pm F_i'$, i.e., it is assumed to be a Coulomb friction force. As long as $-F_i' < F_i < F_i'$, the suspension spring for system i remains inactive and $\dot{s}_i = \ddot{s}_i = 0$. Hence $F_{di}=0$. On the other hand, if $|F_i|=F_i'$, that is when $F_i'=F_i' \frac{\dot{s}_i}{|\dot{s}_i|}$ the suspension spring becomes active and the damping force comes into play.

The equation of motion of the unsprung mass M_i is established by considering the mass itself as a free body as shown in Fig. 2b; thus one obtains

$$M_i \ddot{X}_i = W_i + Q_i - F_{ti} \qquad i = 1,2 \tag{16}$$

where

$$Q_i = F_{di} + F_{si} + F_i \tag{17}$$

Now the forces F_{si}, F_{di}, F_{ti} can all be expressed in terms of the strut stroke s_i and its first time derivative $\dot{s}_i$ and these in turn can be expressed in terms of the coordinate X_i and its time derivative according to Eq. (11).

Numerical Integration Procedure (31), (32)

The equations of motion of the unsprung masses Eq. (16) and those of the airframe Eqs. (7), (8), (9), form a set of nonlinear differential equations of motion equal in number to the number of degrees of freedom of the airframe - landing gear system. These equations are solved numerically by means of a step by step method of integration. The time required for the airplane to traverse a certain distance of the runway is divided into a number of short intervals Δt. Let it be assumed that the values of the displacement, velocity and acceleration of each coordinate of the system are known at a time $t-\Delta t$ and it is desired to find the corresponding values at time t. The method used to accomplish this is the Linear Acceleration Method. In order to avoid iteration each time increment, some approximations have been introduced into the nonlinear system. First, over each small time increment, the nonlinear time dependent damping force is approximated by

$$F_{di} = \frac{\dot{s}_i}{|\dot{s}_i|} \left[D_i(s_i)\dot{s}_i \right]_{t-\Delta t} (\dot{s}_i)_t \tag{18}$$

The quantity in the square bracket is evaluated at the time instant $t-\Delta t$. Second, the spring force in the suspension system is piece-wise linearized. Thus,

$$F_{si} = (k_{1i})_{t-\Delta t} (s_i)_t + (k_{2i})_{t-\Delta t} \tag{19}$$

where

$$(k_{1i})_{t-\Delta t} \text{ and } (k_{2i})_{t-\Delta t}$$

are evaluated at the instant $t-\Delta t$.

With these approximations introduced, the equations of motion of the system are linearized at each instant of time and can be arranged to be put in the following form.

$$\left[M\right] \left\{X\right\} + \left[C\right] \left\{\dot{X}\right\} + \left[K\right] \left\{X\right\} = \left\{R\right\}_t \tag{20}$$

where $\left\{X\right\}$ is the displacement vector of the system,

$\left\{\dot{X}\right\}$ is the velocity vector of the system,

$\left\{\ddot{X}\right\}$ is the acceleration vector of the system,

$\left\{R\right\}$ is the "forcing function" vector of the system,

$\left[M\right]$ is the mass matrix,

$\left[C\right]$ is the damping matrix,

$\left[K\right]$ is the stiffness matrix .

The linear acceleration method is based on the assumption that the acceleration of each coordinate of the system varies linearly within a time increment Δt. The velocity and displacement of each coordinate at the end of the interval are then determined in terms of the known acceleration, velocity and displacement at the beginning of the interval and in terms of the unknown acceleration at the end of the interval, thereby

$$\left\{\dot{X}\right\}_t = \left\{\dot{X}\right\}_{t-\Delta t} + \frac{\Delta t}{2} \left\{\ddot{X}\right\}_{t-\Delta t} + \frac{\Delta t}{2} \left\{\ddot{X}\right\}_t \tag{21}$$

$$\left\{X\right\}_t = \left\{X\right\}_{t-\Delta t} + \Delta t \left\{\dot{X}\right\}_{t-\Delta t} + \frac{\Delta t^2}{3} \left\{\ddot{X}\right\}_{t-\Delta t} + \frac{\Delta t^2}{6} \left\{\ddot{X}\right\}_t \tag{22}$$

The unknown acceleration is evaluated by satisfying the equations of motion of the system at the end of the time interval, that is at time instant t. Thus, substituting Eqs. (21) and (22) into Eq. (20) yields the following equation for the acceleration at the end of the time interval.

$$\left\{\ddot{X}\right\}_t = \left[T\right]\left(\left\{R\right\}_t - \left[c\right]\left\{a\right\} - \left[K\right]\left\{b\right\}\right) \tag{23}$$

where

$$\left[T\right] = \left(\left[M\right] + \frac{\Delta t}{2}\left[c\right] + \frac{\Delta t^2}{6}\left[K\right]\right)^{-1} \tag{24}$$

$$\left\{a\right\} = \left\{\dot{X}\right\}_{t-\Delta t} + \frac{\Delta t}{2}\left\{\ddot{X}\right\}_{t-\Delta t} \tag{25}$$

$$\left\{b\right\} = \left\{X\right\}_{t-\Delta t} + \Delta t\left\{\dot{X}\right\}_{t-\Delta t} + \frac{\Delta t^2}{3}\left\{\ddot{X}\right\}_{t-\Delta t} \tag{26}$$

The velocity and displacement at the end of the interval can now be obtained using Eqs. (21) and (22).

The initial displacement and the initial velocity are given as the initial conditions of the problem and the initial acceleration is determined from Eq. (23) as

$$\left\{\ddot{X}\right\}_0 = \left[M\right]^{-1}\left(\left\{R\right\}_0 - \left[C\right]\left\{\dot{X}\right\}_0 - \left[K\right]\left\{X\right\}_0\right) \tag{27}$$

The step-by-step response of the system is given by repeated application of Eqs. (21), (22), (23), and (24).

It is to be noted that because of the Coulomb friction force in the landing gear systems, a distinction must be made between the case when the absolute value of the Coulomb friction force in a particular landing gear system has reached its limiting frictional value and the case when the absolute value of the Coulomb friction force is smaller than its limiting value. For the latter case the Coulomb friction force must be treated as an unknown quantity and an additional condition must be imposed on the system; that is, there is no relative motion between the unsprung mass of that landing gear system and the landing gear attachment point on the airframe. Thus, the solution of the equations of motion are obtained according to whether $|F_i|$ is smaller than or equal to F'_i and is described as follows:

1. Both landing gears are unlocked, that is $|F_i| = F_i'$, $i=1,2$ — Express F_{si}, F_{di} and hence Q_i in terms of the coordinates of the system and their derivatives according to Eqs. (19), (18), (17), (11). Substituting these Eqs. into the Eqs. of motion (7), (8), (9), (16) and, after rearranging, gives Eq. (20) where $\left[M\right]$ $\left[C\right]$ $\left[K\right]$ are symmetric and their respective elements are given below:

$$M_{ij} = M_i \; ; \; j=i \; ; \; i=1,- - - -N$$

$$M_{ij} = 0 \; ; \; j \neq i \; ; \; i=1,- - - -N \tag{28}$$

$$c_{12} = 0$$

$$c_{ii} = G_i \; ; \; i=1,2$$

$$c_{ij} = -G_i \phi_i^j \; ; \; i=1,2 \; ; \; j=3,- - - -N$$

$$c_{ij} = \sum_{k=1}^{2} G_k \phi_k^i \phi_k^j + c_i \delta_{ij} \; ; \; i=3, - - - -N \; ; \; j=i, - - - -N \tag{29}$$

where $G_i = \left| \left[D_i(s_i)\dot{s}_i \right]_{t-\Delta t} \right|$ (30)

δ_{ij} is the Kronecker Delta function, that is, $\delta_{ij} = \begin{cases} 1, & i=j \\ 0, & i \neq j \end{cases}$ (31)

and $c_i = 2\lambda M_i \omega_i$ (32)

$$K_{12} = 0$$

$$K_{ii} = K_{li} + K_{ti} \; ; \; i=1,2$$

$$K_{ij} = -K_{li} \phi_i^j \; ; \; i=1,2 \; ; \; j=1,- - - - N$$

$$K_{ij} = \sum_{k=1}^{2} K_{ik} \phi_k^i \phi_k^j + M_i \omega_i^2 \delta_{ij} \; ; \; i=3, - - - N \; ; \; j=i, - - - N \tag{33}$$

$\left\{R\right\}$ of Eq. (20) are

$$R_i = W_i + F_i' + \bar{F}_{si} - K_{ti} (\bar{X}_i + h_i) \; ; \; i=1,2$$

$$R_j = -\sum_{i=1}^{2} (L_i \phi_{i+2}^j + F_i' \phi_i^j) \; ; \; j=3, - - - N \tag{34}$$

where $\bar{F}_{si}$ denotes the static value of F_{si}.

Application of the linear acceleration method yields the displacements, velocities and accelerations in the system. The force elements F_{ti}, F_{si}, and F_{di} in the tire-landing gear system can then be obtained using Eqs. (12) (19), and (18).

2. Both landing gears are locked, that is $|F_i| < F_i'$, i=1,2 — In this case the total interacting forces between the landing gears and the airframe, Q_i, i=1,2 are first obtained using Eq. (16), the equations of motion of the unsprung masses, and substituted into Eqs. (7), (8) and (9), the equations of motion of the airframe, thus giving N-2 differential equations in terms of the N coordinates of the system. Two additional conditions are introduced as follows:

$$\ddot{X}_i = \sum_{j=3}^{N} \ddot{X}_j \phi_i^j \; ; \; i=1,2 \tag{35}$$

Thus one gets, after rearranging, a set of N differential Eqs. (20) where the elements of the matrices $\left[M\right]$, $\left[c\right]$, and $\left[K\right]$ are as follows:

$$M_{ii} = -M_i \; ; \; i=1,2$$

$$M_{12} = 0$$

$$M_{ij} = -M_i \phi_i^j \; ; \; i=1,2 \; ; \; j=3, - - - N$$

$$M_{ii} = M_i \; ; \; i=3,- - - N$$

$$M_{ij} = 0 \; ; \; i=3,- - - N \; ; \; j=i+1,- - - N \tag{36}$$

$$c_{ii} = c_i \; ; \; i=3,- - - N$$

Otherwise $c_{ij} = 0$ (37)

$$K_{ij} = 0 \; ; \; i=1,2 \; ; \; j=i,- - - N$$

$$K_{ij} = \sum_{k=1}^{2} K_{tk} \phi_k^j \phi_k^i + \delta_{ij} M_i \omega_j^2 \; ; \; i=3,- - - N \; ; \; j=i,- - - N \tag{38}$$

The elements of the column matrix $\left\{R\right\}$ are

$$R_j = 0 \; ; \; j=1,2$$

$$R_j = -\sum_{i=1}^{2} \left[L_i \phi_{i+2}^j + \phi_i^j \left(K_{ti} \left(\bar{X}_i + h_i - Z_{oi} \right) - W_i - \bar{F}_{si} \right) \right] ; j=3, - - N \qquad (39)$$

where Z_{oi} is the stroke shortening of the ith landing gear.

The solution of the above equations of motion gives the displacement, velocity and acceleration of the system as before. The Coulomb friction forces are obtained from Eqs. (16) and (17) and the remainder of the forces in the tire-landing gear systems are obtained using Eqs. (12), (18), and (19).

3. The main landing gear is unlocked and the nose landing gear is locked; that is, $|F_1| = F_1'$ and $|F_2| < F_2'$. In this case, Q_2, the interacting force between the nose landing gear and the airframe is obtained from Eq. (16), the equation of motion of the nose landing gear. Substituting the Q_i's into the equations of motion of the airframe and Q_i into the equation of motion of the main landing gear, rearranging, one obtains a set of N-1 differential equations of motion in terms of the N coordinates. The additional necessary condition is obtained by imposing the condition

$$\ddot{X}_2 = \sum_{j=3}^{N} \ddot{X}_j \phi_2^j \qquad (40)$$

resulting in N equations in the N coordinates, Eq. (20). The elements of the matrices are:

$$M_{ii} = -(-1)^i M_i \; ; \; i=1,2$$

$$M_{ij} = 0 \; ; \; j=2, - - -N$$

$$M_{2j} = M_2 \phi_2^j \; ; j=3, - - -N$$

$$M_{ii} = M_i \; ; \; i=3, - - -N$$

$$M_{ij} = 0 \; ; \; i=3, - - -N \; ; \; j=i+1, - - -N \qquad (41)$$

$$c_{11} = G_1$$
$$c_{12} = 0$$
$$c_{1j} = -G_1 \phi_1^j \ ; \ j=3, - - -N$$
$$c_{2j} = 0 \ ; \ j=2, - - -N$$
$$c_{ij} = G_1 \phi_1^j \phi_1^i + \delta_{ij} c_j \ ; \ i=3, - - -N \ ; \ j=i, - - -N \qquad (42)$$

$$K_{11} = K_{t1} + k_{11}$$
$$K_{12} = 0$$
$$K_{1j} = -k_{11} \phi_1^j \ ; \ j=3, - - -N$$
$$K_{2j} = 0 \ ; \ j=2, - - -N$$
$$K_{ij} = k_{11} \phi_1^i \phi_1^j + K_{t2} \phi_2^i \phi_2^j + \delta_{ij} M_j \omega_j^2 \ ; \ i=3, - - -N \ ; \ j=i, - - -N \qquad (43)$$

For $\left\{R\right\}$

$$R_1 = W_1 + F_1' + \bar{F}_{si} - K_{ti} (\bar{X}_1 + h_1)$$
$$R_2 = 0$$
$$R_j = -L_1 \phi_3^j - L_2 \phi_4^j - \phi_1^j F_i' - \phi_2^j \left[K_{t2} (\bar{X}_2 + h_2 - Z_{o2}) - W_2 - \bar{F}_{s2} \right]$$
$$j=3- - - -N \qquad (44)$$

The solution of the above equations of motion gives the value of the displacements, velocities and accelerations of the system. The Coulomb friction force F_2 of the nose landing gear is determined from Eqs. (16) and (17). All other forces in the two tire-landing gear systems are obtained through Eqs. (12), (18), and (19).

4. The nose landing gear is unlocked and the main landing gear is locked; that is $|F_2| = F_2'$, $|F_1| < F_1'$ – This case is similar to the case described in 3. Following the procedures described in 3, we arrive at Eq. (20). The $\left[M\right]$, $\left[c\right]$, $\left[K\right]$ and $\left\{R\right\}$ matrices of the resulting equation (20) can be obtained from the corresponding matrices for the cases described in 1, 2, and 3, namely, each matrix in this case is equal to the sum of the corresponding matrix in

cases 1 and 2 minus that in case 3. Having solved the equations of motion the Coulomb friction force of the main landing gear is obtained using Eqs. (16) and (17). The rest of the forces in the tire-landing gear systems are obtained through Eqs. (12), (18) and (19).

Computer Program

The method described in the previous section has been programmed for the IBM 7090 digital computer. The program consists of five parts described as follows:

Part 1. The purposes of the program "Profile" are

(a) to compute, from the profile elevations of a given runway, the profile elevations at the main and nose wheels at each successive instant of time according to the time interval (or intervals) chosen for the computation of the response of the airplane and the time history of the speed of the airplane during take-off and landing;

(b) to compute, from the time history of the speed of the airplane on the runway, the speed of the airplane at each successive instant of time so one can determine the aerodynamic lift forces; and

(c) to compute, from the time history of the angles of attack at both the wings and the canard, the values of these quantities at each successive instant of time for the same purpose as described in (b).

The above three sets of data are read into the Computer using cards and the program carries out the interpolation. Because of the limited storage capacity of the computer, after a certain number of cycles of interpolation say, JP, is completed, the results are printed on line and transferred to tape for use in the "Response" program described in Part 2. The interpolation process is repeated until the program reaches the end of the runway.

Part 2. The purpose of the program "Response" is to compute the dynamic response of a given airplane operating on the given runway.

This program starts with the reading in of data which specifies the physical characteristics of the airplane including the initial conditions of the system. Next, the interpolated values of the time history of the airplane velocity on the runway, the profile elevations at the main and nose wheels, and the time history of the angles of attack at the wings and the canard are read in from tape according to the manner in which it was recorded on the tape by the program "Profile".

The main function of the "Response" program is to integrate numerically the equations of motion according to whether $|F_i| = F_i'$ or $|F_i| < F_i'$ for i=1,2. Again, because of the limited storage capacity of the computer, the data, other than those of the characteristics of the airplane and the initial conditions, are read in piece by piece and the results of the integration are transferred to tape after each piece of data is exhausted.

The output information includes the time history of the generalized or normal coordinates of the system, their first and second derivatives, and includes the tire forces of the main and nose wheels. These quantities are considered "essential" and are retained on tape since whatever quantity is required for the airplane such as stress at any location, it can be readily calculated from the information stored on such tape. Also, the vertical acceleration at the pilot location can be obtained from the equation:

$$\ddot{W}(L,o,t) = \sum_{j=3}^{N} \ddot{X}_j(t)\, \phi_5^j \tag{45}$$

where ϕ_5^j is the value of the jth mode shape at the pilot location.

Part 3. The program "Plotxy" is written to make use of a Cal-Comp plotter which will automatically plot the time history curves of the generalized coordinates, their first and second derivatives, and will also plot the vertical displacements, velocities and accelerations at the pilot's compartment.

This program starts by reading in control data that specify which of the

above mentioned time history curves are to be plotted and the scale to be used for each curve. The values of the elastic mode shapes at the pilot's compartment are also read in in order to determine the displacements, velocities, and accelerations at the position of the pilot as indicated by Eq. (45) in Part 2.

The program then reads from the output tape of the "Response" program values of the quantities that are to be plotted. The displacements, velocities, and accelerations of the pilot's compartment are calculated if specified. The program then makes use of the IBM 7090 library routine J6 BC XYP2 to activate plotting instruments and transfer them to a Cal-Comp data tape which is then read by a 1401 program and used to drive the plotter.

Part 4. Similar to the program "Plotxy", the program "PlotF" also makes use of the 7090 library routine J6 BC XYP2 and the Cal-Comp plotter to plot the time history curves of the tire forces of the main and nose landing gears.

This program then reads in control data that specify which of the above mentioned curves will be plotted and the scales to be used for each curve. The values of the static tire forces of the main and nose landing gears are also read into the computer by this program and then the values of the total tire forces are read in from the output tape of the "Response" program. The static forces are then subtracted from their corresponding total forces. The resulting curves plotted therefore represent the fluctuation of the tire forces about their static values.

Part 5. The program "Stat" is intended to compute the time averages of the response of the airplane on the runway. Computed are the peak, mean and mean square values of the coordinates of the system as well as their derivatives, and peak, mean and mean square values of the displacements, velocities and accelerations of the pilot-s compartment and the fluctuation of the tire forces about their static values are also computed. The peak values of the

quantities mentioned above not only indicate the maximum absolute values of the quantities but also furnish information regarding the scales to be selected in the "Plotxy" and "PlotF" programs as described in Part 3 and Part 4 respectively.

It is to be noted that the time histories of the quantities mentioned above have statistical significance only when the airplane operates on sufficiently long runways at constant speed in which case they then constitute ergodic processes. The results presented in the following section should therefore be interpreted accordingly.

A detailed listing of the programs described above is included in Appendix 1.

Discussion of Results

The dynamic response of the Boeing 707 and the Boeing 733 94 on two runways have been obtained. The pertinent characteristics of these two airplanes are contained in Appendix 2. Runway profile data are tabulated in Tables 1 and 2 and plotted in Fig. 3. Runway 12 is plotted about a zero arithmetic mean and Runway 28R is plotted with reference to a datum 10 feet above mean sea level

For each airplane, the response was first determined with the inclusion of six flexural modes and was then determined considering rigid body motion only. In the entire investigation, all aerodynamic lift forces were assumed to be non-existent. The time history curves of response include the vertical displacement of nose and main landing gear wheels, the vertical displacement of the center of gravity of the airplane (rigid body translational mode), the rigid body pitching angle, the vertical displacement at the location of pilot. the vertical acceleration at the location of pilot, and the tire forces of the main and nose landing gears. In the case when flexural modes of the airframe are included. the time history curves of the generalized coordinates of the flexural modes are also presented. In addition to the time history curves of response of the airplane, the peak values of response, their respective mean values, and their

mean square values have been obtained by means of the "Stat" program for those cases where the velocity of the airplane is held constant. These results are given in Tables 3 and 4.

The computer time required to obtain a solution depends on the particular problem considered. It depends on the length of the runway, the speed of the airplane, and the time interval chosen for the numerical integration procedure. Different time intervals were used in test runs and comparison of the results showed that the desired degree of accuracy was obtained for all cases using the time interval 0.002 seconds. The following is an estimate of the time required for the solution of the 707 airplane operating with a constant velocity v=100 ft/sec on Runway 12 which has a length of 3000 ft. The time required for the "Response" program was approximately 30 minutes for the case when all six flexural modes were included and 9 minutes for the case when only rigid body motion were considered in the computation. The average time required for the "Plotxy" and "PlotF" programs to plot one curve on each graph was about 2 minutes and the time required for the "Stat" program ranged between 1.5 and 2.0 minutes depending on whether flexural modes were considered in the computation or not.

Although there has been insufficient time to carry out detailed investigations and the basic data reflecting the characteristics of the supersonic transport are based on an earlier design which is not considered final, the limited information obtained does indicate some significant phenomena which are discussed as follows:

1. Rigid Body Translation - The time history curves for rigid body translation of both airplanes operating on each runway are shown in Fig. 11 for the case when flexural mode response is included and in Fig. 12 when only rigid body response is included. In each of these figures, the displacement consists of an oscillatory motion having a predominant frequency of approximately 1.3 cps superimposed upon a displacement corresponding to the runway profile. Note that

the runway profile elevation h as plotted in Fig. 3 is considered positive when upwards while the vertical displacement of the center of gravity (rigid body translation) is considered positive when downwards. Therefore, the runway profile contributions to the displacements shown in Figs. 11 and 12 appear in an inverted form from those profile elevations of Fig. 3.

Because of the large non-linearities present in the entire structural system, it is difficult to completely identify the predominant frequencies appearing in Figs. 11 and 12. One significant quantitative observation, however, is the fact that the inclusion of flexural modes in the dynamic response reduces somewhat the magnitude of the rigid body translation.

It should be noted in both Figs. 11 and 12 that the rigid body translational response is considerably greater for the 733-94 airplane as compared with the 707 airplane.

It will also be noted that there is greater dynamic peak response of both airplanes on Runway 12 at locations of large discrete bumps than on Runway 28R of the San Francisco International Airport where the discrete bumps are less severe.

2. Rigid Body Rotation - The time history curves for rigid body rotation are shown in Figs. 13 and 14. The predominant frequency of this type of motion is approximately 1.0 cps and 0.5 cps for the 707 and 733-94 airplanes, respectively. These results show that the flexural modes do not appreciably affect this type of response except for the case of the 733-94 airplane operating on Runway 28R where inclusion of the flexural modes resulted in a considerable reduction of response.

Generally it is observed that the peak rigid body rotation of the 733-94 airplane is greater than the rotation of the 707 airplane especially on Runway 12 where the large discrete bumps near the end of the runway are critical (see Fig. 3).

3. Vertical Displacement at Pilot Location - The time history curves for vertical displacement at the pilot location are shown in Figs. 19 and 20. In each

figure the total displacement as contributed by all modes is shown along with the individual contribution of the rigid-body translational and the rigid body rotational modes. A study of the separate contributions shows that the total displacements for both airplanes is due primarily to the rigid body rotational contribution, especially on Runway 12. Note that the runway profile displacements must be reflected in this observation as before in the case of rigid body translation (see Section 1 above). The discrete bumps near the end of Runway 12 are the cause of the large peak displacements produced which are quite large in a relative sense for the case of the 733-94 airplane.

4. Vertical Acceleration at Pilot Location - The time history curves for vertical acceleration at the pilot location are shown in Figs. 21 and 22. It is immediately apparent upon inspecting these results that the influence of the flexural modes upon peak accelerations and upon frequency distribution is appreciably, i.e. the inclusion of flexible mode response gives considerably higher accelerations at higher frequencies. The effects of these accelerations on pilots needs investigation.

It is apparent from these results that the peak vertical acceleration at the pilot location is considerably larger for the 733-94 airplane as compared with the 707 airplane. Peak accelerations have been observed in this investigation as high as 1.6g and 2.4g for the 707 and the 733-94 airplanes, respectively.

For Runway 12 where both airplanes were operated at a constant speed of 100 ft/sec the root mean square accelerations at the pilot locations were 0.25g and 0.54g, respectively, for the 707 and 733-94 airplanes. The root mean square accelerations at the C.G. location were 0.13g and 0.19g, respectively. Therefore, it is necessary to include both rigid body and flexural modes in evaluating acceleration response.

5. Main Landing Gear Tire Force - The time history curves for the main landing gear tire force are shown in Figs. 23 and 24. This tire force represents the total of the forces exerted by both main landing gears on the runway pavement. For both airplanes it has been assumed that all main landing gear wheels are located on a single horizontal axis. In the case of large transport airplanes, the forward and rear wheels in the main landing gear truck are spaced approximately 5 ft. apart in the longitudinal direction. However, the error introduced in the analysis by assuming both forward and rear wheels to be on a single axis is considered negligible since only the relatively long profile wave lengths (50-100 ft) produce major dynamic response.

Comparing the results of Figs. 23 and 24 shows that the flexibility of the aircraft, brought into the analysis by including the flexible modes, considerably reduces the peak tire forces. The predominant frequencies shown in these figures are in the same narrow frequency band as in the case of the rigid body translation previously discussed.

The ordinate force scale shown on Figs. 23 and 24 actually represents the increase or decrease in tire force from its static equilibrium value which is indicated on each graph. One will note on these figures that the total main tire force in each case reaches peak intensities as much as 1.65 times static equilibrium value when all modes including flexural are considered in the analysis.

6. Nose Landing Gear Tire Force - The time history curves for the nose landing gear tire force are shown in Figs. 25 and 26. This tire force represents the total nose landing gear force exerted on the runway pavement.

The effect of including the flexural modes in the dynamic analysis reduces considerably the peak nose tire forces. Peak nose tire forces obtained when including flexural modes, were 2.38 and 4.28 times their static equilibrium values for the 707 and 733-94 airplanes, respectively.

The nose wheel is observed to lift off the runway pavement in some instances, i.e. where the tire force maintains a negative value equal to the static equilibrium value. In these instances a flat segment of the curves is noticeable. It is apparent that the 733-94 airplane has more tendency to lift its nose tire off the runway than does the 707 airplane. The pilot can, or course, prevent such lift off by increasing the static equilbirium value which can be done by introducing an aerodynamic steady state pitching moment.

7. Generalized Coordinates of Flexible Modes - The time history curves of the generalized coordinates of the first six flexural-symmetric-free-free modes of the airframe are presented in Figs. 15 - 18. A study of these results shows that the higher flexible modes are of more importance for the 733-94 airplane than for the 707 airplane. While six flexible modes have been used in this analysis, one could use fewer of these modes in some instances especially for the 707 airplane. However in generating some quantities, such as vertical acceleration at the location of pilot, it would appear advisable to retain all six modes.

III STATISTICAL APPROACH

General

Although the effects of discrete runway bumps on the response of an airplane can be conveniently studied by the deterministic approach previously presented, a statistical study of the more stationary unevenness effects can be very helpful to the design engineer particularly in evaluating fatigue damage of the structural system.

A statistical study of the airplane response while traveling over the entire length of a collection or ensemble of runways by means of digital computer methods requires much computer time. However, a more promising and direct approach to this problem appears to be the power spectral approach.

A power spectrum of a runway profile characterizes the essential aspects of the profile; therefore by compiling the spectra of many different runways one can establish a means for judging the severity of runway unevenness. Much work has been done in this area (3 - 8). Various means of measuring runway unevenness have been devised, power spectral data have been prepared for many different runways, and criteria have been established to classify runways as being rough, medium or smooth.

Statistical studies of the airplane response utilizing available power spectral data has been done by some authors. If one assumes linear landing gear systems, an analytical solution of the airplane response is easily obtained; however, typical landing gear systems are quite nonlinear especially at higher speeds (10); thus, making statistical solutions very difficult to obtain. It is the intent of the study of this section to try to arrive at a technique which can take into account the nonlinearities in the landing gear system when carrying out direct statistical solutions.

For the class of problems in which the system is subjected to normal stationary white noise excitation and the nonlinearities involve only displacements of

the system, it has been shown (27) that exact solutions can be constructed for the stationary Fokker-Plank equation.

Inasmuch as the system under consideration involves nonlinearities both in the displacements as well as in the velocities and the random excitation is non-white and need not be stationary, the above technique does not apply. Approximate techniques have been developed to handle random vibration of nonlinear systems (28), (29).In a paper presented at the Symposium of the Acoustical Society of America, S. Crandall discussed the application of the perturbation techniuqe for random vibration of nonlinear systems. In the same issue T. Caughey discussed the application of equivalent linearization technique to nonlinear systems with random excitation.

An examination of both techniques shows that neither method is directly applicable to the problem in hand.

In the following discussion the perturbation method as presented by Crandall is first reviewed and extended to the case of multidegree systems. Second, the principle of the equivalent linearization method as presented by Caughey is also re-stated and a possible combination of the two methods for obtaining an engineering solution of the airplane problem is discussed.

<u>The Perturbation Method</u> (28)

Consider a system with one-degree of freedom whose equation of motion is of the form

$$\ddot{x} + \beta\dot{x} + \omega_0^2 (x + \kappa g (x,\dot{x})) = f(t) \tag{46}$$

where $g(x,\dot{x})$ is a nonlinear function of x and $\dot{x}$ and κ is a small perturbation factor.

If one attempts to solve this equation by the power series solution

$$x = x_0 + \kappa x_1 + \kappa^2 x_2 + - - - - - \tag{47}$$

$$\dot{x} = \dot{x}_0 + \kappa \dot{x}_1 + \kappa^2 \dot{x}_2 + - - - - - \tag{48}$$

then

$$g(x,\dot{x}) = g(x_0 + \kappa x_1 + \kappa^2 x_2 + - - - -, \dot{x}_0 + \kappa\dot{x}_1 + \kappa^2\dot{x}_2 + - - - -)$$
$$= g(x_0,\dot{x}_0) + \kappa(x_1 g_x(x_0,\dot{x}_0) + \dot{x}_1 g_{\dot{x}}(x_0,\dot{x}_0)) + - - - - \qquad (49)$$

Substitution of Eqs. (47), (48), and (49) into Eq. (46) and equating the coefficients of like powers of κ yields the following recursive system:

$$\ddot{x}_0 + \beta\dot{x}_0 + \omega_0^2 x_0 = f(t) \qquad (50)$$

$$\ddot{x}_1 + \beta\dot{x}_1 + \omega_0^2 x_1 = -\omega_0^2\, g(x_0,\dot{x}_0) \qquad (51)$$

$$\ddot{x}_2 + \beta\dot{x}_2 + \omega_0^2 x_2 = -\omega_0^2\, (x_1 g_x(x_0,\dot{x}_0) + \dot{x}_1 g_{\dot{x}}(x_0,\dot{x}_0)) \qquad (52)$$

Solution of Eq. (50) can be represented by the convolution integral

$$x_0(t) = \int_0^\infty f(t-\tau)\, h(\tau)\, d\tau \qquad (53)$$

where $h(\tau)$ is the unit impulse response

$$h(\tau) = \frac{1}{\omega_d}\, e^{-\beta\tau/2} \sin \omega_d\tau \;;\quad \omega_d = \sqrt{\omega_0^2 - \beta^2/4} \qquad (54)$$

Similarly,

$$x_1(t) = -\omega_0^2 \int_0^\infty h(\tau)\, g(x_0(t-\tau),\dot{x}_0(t-\tau))\, d\tau \qquad (55)$$

The quantities $x_2(t)$, $x_3(t)$ etc. can be obtained in a similar manner.

For purposes of illustration, let the excitation $f(t)$ be a stationary Gaussian random process with known statistical properties and $g(x,\dot{x})=g(x)=x^3$. Accepting as an approximate solution to Eq. (46)

$$x = x_0 + \kappa x_1 \qquad (56)$$

$$\dot{x} = \dot{x}_0 + \kappa\dot{x}_1 \qquad (57)$$

the mean square of x is

$$< x^2 > = < x_0^2 > + 2\kappa < x_0 x_1 > \qquad (58)$$

correct to the first order in κ. Here $< >$ designates the ensemble average of the quantity enclosed in it. From Eq. (53)

$$< x_0^2 > = \int_0^\infty \int_0^\infty h(\tau_1)\, h(\tau_2) < f(t-\tau_1)\, f(t-\tau_2) > d\tau_1\, d\tau_2$$
$$= \int_0^\infty \int_0^\infty h(\tau_1)\, h(\tau_2)\, R_f(\tau_1-\tau_2)\, d\tau_1\, d\tau_2 \qquad (59)$$

where $R_f(\tau_1-\tau_2)$ is the autocorrelation function of the stationary excitation process with argument $\tau_1-\tau_2$. Similarly, from Eqs. (53) and (55)

$$< x_o x_1 > = \omega_d^2 \int_0^\infty h(\tau_1)\, h(\tau_2) < x_0(t) x_0^3\,(t-\tau) > d\tau \qquad (60)$$

In the case where a stationary random process z(t) is Gaussian with a mean of zero we have (22)

$$< z(t_1) > = 0$$

$$< z(t_1)\, z(t_2) > = R_z\,(t_1-t_2)$$

$$< z(t_1)\, z(t_2)\, z(t_3)> = 0$$

$$< z(t_1)\, z(t_2)\, z(t_3)\, z(t_4)> = R_z\,(t_1-t_2)\, R_z(t_3-t_4) + R_z(t_1-t_3)\, R_z(t_2-t_4) + R_z(t_1-t_4)\, R_z(t_2-t_3) \qquad (61)$$

Since the output process of a linear system whose input is a Gaussian stationary process is also a Gaussian stationary process, one obtains, from Eq. (61)

$$< x_0(t)\, x_0^3(t-\tau)> = 3 < x_0(t-\tau)\, x_0\,(t-\tau) > < x_0(t)\, x_0(t-\tau) > \qquad (62)$$

Using the fact that for a stationary process x_0, the ensemble average

$$<x_0(t)\, x_0\,(t-\tau) > = R_{x0}(\tau) = \int_0^\infty \int_0^\infty h(\tau_1)\, h(\tau_2)\, R_f(\tau+\tau_1-\tau_2)\, d\tau_1\, d\tau_2 \qquad (63)$$

and also using the fact that

$$< x_0(t-\tau)\, x_0(t-\tau) = R_{x0}(0) \qquad (64)$$

one can establish that

$$< x_0(t)\, x_1(t) > = -3\omega_0^2\, R_{x0}(0) \int_0^\infty h(\tau)\, R_{x0}(\tau)\, d\tau \qquad (65)$$

Thus, from Eq. (58)

$$< x^2 > = R_{x0}(0) \left[1 - 6\kappa\omega_0^2 \int_0^\infty h(\tau)\, R_{x0}(\tau)\, d\tau \right] \qquad (66)$$

Suppose now the excitation process is a Gaussian stationary random process whose power spectral density function is white, i.e.

$$R_f(\tau) = \delta(\tau) \qquad (67)$$

where $\delta(\tau)$ is the Dirac Delta function, one now obtains, using Eq. (63)

$$R_{x0}(\tau) = \sigma_{x0}^2 \, e^{-\beta\tau/2} \left(\cos \omega_d \tau + \frac{\beta}{2\omega_d} \sin \omega_d \tau\right) \tag{68}$$

and upon substituting Eq. (68) into Eq. (66), one gets

$$< x^2 > = \sigma_{x0}^2 - 3\kappa\sigma_{x0}^4 \tag{69}$$

where

$$\sigma_{x0}^2 = \frac{1}{2\omega_0^2\beta} \tag{70}$$

<u>Application of the Perturbation Method to Multi-degree of Freedom Systems Subjected to Random Inputs</u> (28), (26).

Consider an N-degree of freedom system whose equations of motion are

$$\left[m\right]\left\{\ddot{z}\right\} + \left[c\right]\left\{\dot{z}\right\} + \left[k\right]\left\{z\right\} + \kappa\left\{g(z_1, z_2, ---\dot{z}_1, \dot{z}_2, ---)\right\} = \left\{f(t)\right\} \tag{71}$$

where $\left\{g(z_1, z_2, ---\dot{z}_1, \dot{z}_2, ---)\right\}$ is a nonlinear function and κ is a small perturbation factor. As in the case of single-degree of freedom systems, let the solution of this set of equations be represented by

$$\left\{z\right\} = \left\{x\right\} + \kappa\left\{y\right\} \tag{72}$$

$$\left\{\dot{z}\right\} = \left\{\dot{x}\right\} + \kappa\left\{\dot{y}\right\} \tag{73}$$

where accuracy is assumed acceptable to the first order perturbation. Then, the mean square of z_i would be

$$< z_i > = < x_i^2 > + 2\kappa < x_i y_i > \qquad ; \; i=1, ----N \tag{74}$$

correct to the first order in κ. Expanding $\left\{g(z_1, z_2, ---\dot{z}_1, \dot{z}_2, ---)\right\}$ as

$$\left\{g(z_1, z_2, ---\dot{z}_1, \dot{z}_2 ---)\right\} = \left\{g(x_1 + \kappa y_1, x_2 + \kappa y_2, ---\dot{x}_1 + \kappa\dot{y}_1, \dot{x}_2 + \kappa\dot{y}_2, ---)\right\}$$

$$= \Big\{g(x_1, x_2, ---\dot{x}_1, \dot{x}_2, ---) + \kappa(y_1 g_{z1}\,(x_1, x_2, ---\dot{x}_1, \dot{x}_2, ---) + y_2 g_{z2}\,(x_1, x_2, ---\dot{x}_1, \dot{x}_2, ---)$$

$$+ ----+ \dot{y}_1 g_{z1}\,(x_1, x_2, ---\dot{x}_1, \dot{x}_2, ---) + \dot{y}_2 g_{z2}\,(x_1, x_2, ---, \dot{x}_1, \dot{x}_2, ---) + ---)$$

$$+ \kappa^2\,(-----)\Big\} \tag{75}$$

then substituting Eqs. (72), (73), and (75) into Eq. (71) and equating corresponding coefficients of κ gives

$$\left[m\right]\left\{\ddot{x}\right\} + \left[c\right]\left\{\dot{x}\right\} + \left[k\right]\left\{x\right\} = \left\{f(t)\right\} \tag{76}$$

$$\left[m\right]\left\{\ddot{y}\right\} + \left[c\right]\left\{\dot{y}\right\} + \left[k\right]\left\{y\right\} = -\left\{g(x_1, x_2, \text{------} \dot{x}_1, \dot{x}_2, \text{----})\right\} \tag{77}$$

To make the discussion more general, consider the case in which the system does not necessarily possess classical normal modes. In such cases, we must use a more general approach to the problem (24). Consider Eq. (76), and let

$$\left\{q\right\} = \begin{Bmatrix} \left\{\dot{x}\right\} \\ \left\{x\right\} \end{Bmatrix} \tag{78}$$

$$\left\{F(t)\right\} = \begin{Bmatrix} \left\{0\right\} \\ \left\{f(t)\right\} \end{Bmatrix} \tag{79}$$

$$\left[R\right] = \begin{bmatrix} \left[0\right] & \left[m\right] \\ \left[m\right] & \left[c\right] \end{bmatrix} \tag{80}$$

$$\left[K\right] = \begin{bmatrix} -\left[m\right] & \left[0\right] \\ \left[0\right] & \left[k\right] \end{bmatrix} \tag{81}$$

then Eq. (76) may be rewritten in the form

$$\left[R\right]\left\{\dot{q}\right\} + \left[K\right]\left\{q\right\} = \left\{F(t)\right\} \tag{82}$$

a set of 2N first order differential equations. The homogeneous solutions of Eq. (82) are obtained by assuming

$$\left\{q\right\} = e^{\alpha t}\left\{\Phi\right\} \tag{83}$$

Substituting Eq. (83) into Eq. (82) yields

$$\alpha \left[R\right] \left\{\Phi\right\} + \left[K\right] \left\{\Phi\right\} = \left\{0\right\} \tag{84}$$

or

$$\left[U\right] \left\{\Phi\right\} = \frac{1}{\alpha} \left\{\Phi\right\} \tag{85}$$

where

$$\left[U\right] = \begin{bmatrix} \left[0\right] & \left[I\right] \\ -\left[K\right]^{-1} \left[m\right] & -\left[K\right]^{-1} \left[c\right] \end{bmatrix} \tag{86}$$

and where $\left[I\right]$ is the identity matrix.

For non-trivial solutions of $\left\{\Phi\right\}$ to exist, the following conditions must hold, i.e.

$$\left[U\right] - \frac{1}{\alpha} \left[I\right] = 0 \tag{87}$$

This yields 2N eigenvalues α_n and 2N eigenvectors

$$\left\{\phi^n\right\} = \begin{Bmatrix} \alpha^n \left\{\phi^n\right\} \\ \left\{\phi^n\right\} \end{Bmatrix} \tag{88}$$

If $\left[m\right]$, $\left[k\right]$, $\left[c\right]$ are symmetric, $\left[R\right]$ and $\left[K\right]$ are symmetric and Eq. (84) may be written as

$$\alpha_n \left[R\right] \left\{\Phi^n\right\} + \left[K\right] \left\{\Phi^n\right\} = \left\{0\right\} \tag{90}$$

or

$$\alpha_m \left\{\Phi^m\right\}^T \left[R\right] + \left\{\Phi^m\right\}^T \left[K\right] = \left\{0\right\} \tag{91}$$

Premultiply Eq. (90) by $\left\{\Phi^m\right\}^T$ and postmultiply Eq. (91) by $\left\{\Phi^n\right\}$ to get

$$\alpha_n \left\{\Phi^m\right\}^T \left[R\right] \left\{\Phi^n\right\} + \left\{\Phi^m\right\}^T \left[K\right] \left\{\Phi^n\right\} = \left\{0\right\} \tag{92}$$

and

$$\alpha_m \left\{\Phi^m\right\}^T \left[R\right] \left\{\Phi^n\right\} + \left\{\Phi^m\right\}^T \left[K\right] \left\{\Phi^n\right\} = \left\{0\right\} \tag{93}$$

Subtracting Eq. (93) from Eq. (92) yields,

$$(\alpha_n - \alpha_m) \left\{\Phi^m\right\}^T \left[R\right] \left\{\Phi^n\right\} = 0 \tag{94}$$

Thus, one obtains the orthogonality relations

$$\left\{\Phi^m\right\}^T \left[R\right] \left\{\Phi^n\right\} = 0 \qquad m \neq n \tag{95}$$

$$\left\{\Phi^m\right\}^T \left[K\right] \left\{\Phi^n\right\} = 0 \qquad m \neq n \tag{96}$$

For the nonhomogeneous solution of Eq. (82), let

$$\left\{q(t)\right\} = \sum_{n=1}^{2N} \left\{\Phi^n\right\} \xi_n(t) \tag{97}$$

where $\xi_n(t)$ are to be determined. Substituting Eq. (97) into Eq. (82) yields

$$\sum_{n=1}^{2N} \left[R\right] \left\{\Phi^n\right\} \dot{\xi}_n + \sum_{n=1}^{2N} \left[K\right] \left\{\Phi^n\right\} \xi_n = \left\{F(t)\right\} \tag{98}$$

Premultiplying by $\left\{\Phi^n\right\}^T$ yields

$$\sum_{n=1}^{2N} \left\{\Phi^m\right\}^T \left[R\right] \left\{\Phi^n\right\} \dot{\xi}_n + \sum_{n=1}^{2N} \left\{\Phi^m\right\}^T \left[K\right] \left\{\Phi^n\right\} \xi_n = \left\{\Phi^m\right\}^T \left\{F(t)\right\} \tag{99}$$

Applying the orthogonality relations Eqs. (95) and (96) reduces Eq. (99) to

$$R_n \dot{\xi}_n - \alpha_n R_n \xi_n = F_n(t) \tag{100}$$

where

$$R_n = \left\{\Phi^n\right\}^T \left[R\right] \left\{\Phi^n\right\} = 2\alpha_n \left\{\Phi^n\right\}^T \left[m\right] \left\{\Phi^n\right\} + \left\{\Phi^n\right\}^T \left[c\right] \left\{\Phi^n\right\} \tag{101}$$

and where

$$F_n(t) = \left\{\Phi^n\right\}^T \left\{F(t)\right\} = \left\{\Phi^n\right\}^T \left\{f(t)\right\} \tag{102}$$

The solution of Eq. (100) is obtained by applying the unit impulse method.

Thus,

$$\xi_n(t) = \frac{1}{R_n} \int_0^t e^{\alpha_n (t-\tau)} F_n(\tau)\, d\tau \tag{103}$$

and
$$\left\{q(t)\right\} = \sum_{n=1}^{2N} \left\{\Phi^n\right\} \xi_n(t) = \sum_{n=1}^{2N} \left\{\Phi^n\right\} \frac{1}{R_n} \int_0^t e^{\alpha_n(t-\tau)} F_n(\tau)\, d\tau \tag{104}$$

or
$$\left\{x(t)\right\} = \sum_{n=1}^{2N} \left\{\phi^n\right\} \frac{1}{R_n} \int_0^t e^{\alpha_n(t-\tau)} F_n(\tau)\, d\tau \tag{105}$$

and
$$\left\{\dot{x}(t)\right\} = \sum_{n=1}^{2N} \left\{\phi^n\right\} \frac{\alpha_n}{R_n} \int_0^t e^{\alpha_n(t-\tau)} F_n(\tau)\, d\tau \tag{106}$$

The statistical moments can now be formed, for instance
$$\langle x_i^2 \rangle = \sum_{n=1}^{2N} \sum_{m=1}^{2N} \frac{1}{R_n R_m} \phi_i^n \phi_i^m \int_0^t \int_0^t e^{\alpha_n(t-\tau_1)} e^{\alpha_m(t-\tau_2)} \langle F_n(\tau_1) F_m(\tau_2) \rangle\, d\tau_1 d\tau_2 \tag{107}$$

where $F_n(t)$ is defined by Eq. (102). In a similar manner, using Eq. (77) one obtains
$$\left\{y_i\right\} = \sum_{n=1}^{2N} \left\{\phi^n\right\} \frac{1}{R_n} \int_0^t e^{\alpha_n(t-\tau)} G_n(\tau)\, d\tau \tag{108}$$

where
$$G_n(\tau) = -\left\{\phi^n\right\}^T \left\{g(x_1, x_2, \cdots \dot{x}_1, \dot{x}_2, \cdots)\right\} \tag{109}$$

then
$$\langle x_i y_i \rangle = \sum_{n=1}^{2N} \sum_{m=1}^{2N} \frac{1}{R_n R_m} \phi_i^m \phi_i^n \int_0^t \int_0^t e^{\alpha_n(t-\tau)} \langle x_i(t) G_n(\tau) \rangle\, d\tau \tag{110}$$

where $G_n(\tau)$ is related to $x_1, x_2, \cdots \dot{x}_1, \dot{x}_2, \cdots$ as defined by Eq. (109). The expression of the ensemble average therefore depends on the form of the non-linearity of the system.

To clarify this method further consider the case of an airplane moving with constant velocity v along a runway whose profile may be represented by a stationary random process. Let the airplane be idealized as a two-degree of freedom system (Fig. 27). The terms m_1 and m_2 represent the total mass of the airframe and the total mass of the wheels respectively. The displacements of the two masses are chosen as the generalized coordinates of the system; each being measured from

their respective static equilibrium positions. The tire spring force and the damping force in the landing gear system are assumed to be linear. The spring force in the landing gear system is considered nonlinear and is expressed as

$$F_s = k_1 (z_2 - z_1) + \kappa k_1 (z_2 - z_1)^3 + \bar{F}_s \tag{111}$$

where κ is a small perturbation factor and $\bar{F}_s = m_1 g$ is the static spring force. The equations of motion of the system are then

$$m_1 \ddot{z}_1 + k_1(z_1 - z_2) + c(\dot{z}_1 - \dot{z}_2) + \kappa k_1 (z_1 - z_2)^3 = 0 \tag{112}$$

$$m_2 \ddot{z}_2 - k_1(z_1 - z_2) - c(\dot{z}_1 - \dot{z}_2) - \kappa k_1 (z_1 - z_2)^3 + k_2 z_2 = k_2 \Delta(s) \tag{113}$$

where $\Delta(s)$ is the profile elevation of the runway and $s = vt$. k_2 represents the stiffness of the tire spring. If one considers only first order perturbation, i.e.

$$z_1 = x_1 + \kappa y_1 \tag{114}$$

$$\dot{z}_2 = \dot{x}_2 + \kappa \dot{y}_2 \tag{115}$$

one obtains

$$M_1 \ddot{x}_1 + k_1(x_1 - x_2) + c(\dot{x}_1 - \dot{x}_2) = 0 \tag{116}$$

$$m_2 \ddot{x}_2 - k_1(x_1 - x_2) - c(\dot{x}_1 - \dot{x}_2) + k_2 x_2 = k_2 \Delta(vt) \tag{117}$$

$$m_1 \ddot{y}_1 + k_1(y_1 - y_2) + c(\dot{y}_1 - \dot{y}_2) = -k_1 (x_1 - x_2)^3 \tag{118}$$

$$m_2 \ddot{y}_2 - k_1(y_1 - y_2) - c(\dot{y}_1 - \dot{y}_2) + k_2 y_2 = k_1 (x_1 - x_2)^3 \tag{119}$$

or in matrix form

$$\left[m\right]\left\{\ddot{x}\right\} + \left[c\right]\left\{\dot{x}\right\} + \left[k\right]\left\{x\right\} = \left\{f(t)\right\} \tag{120}$$

and

$$\left[m\right]\left\{\ddot{y}\right\} + \left[c\right]\left\{\dot{y}\right\} + \left[k\right]\left\{y\right\} = \left\{g(t)\right\} \tag{121}$$

where

$$\left[m\right] = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \tag{122}$$

$$\left[c\right] = \begin{bmatrix} c & -c \\ -c & c \end{bmatrix} \tag{123}$$

$$\left[k\right] = \begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1+k_2 \end{bmatrix} \tag{124}$$

$$\left\{f(t)\right\} = \begin{Bmatrix} 0 \\ k_2\Delta(vt) \end{Bmatrix} \tag{125}$$

$$\left\{g(t)\right\} = \begin{Bmatrix} -k_1(x_1(t) - x_2(t))^3 \\ k_1(x_1(t) - x_2(t))^3 \end{Bmatrix} \tag{126}$$

To find the eigenvalues and eigenvectors of the system we formulate the matrix $\left[U\right]$

$$\left[U\right] = \begin{bmatrix} \left[0\right] & \left[I\right] \\ -\left[k\right]^{-1}\left[m\right] & -\left[k\right]^{-1}\left[c\right] \end{bmatrix} =$$

$$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{1}{\omega_1^2} - \frac{1}{\epsilon}\frac{1}{\omega_2^2} & -\frac{1}{\omega_2^2} & -\frac{2\zeta}{\omega_1} & \frac{2\zeta}{\omega_1} \\ -\frac{1}{\epsilon}\frac{1}{\omega_2^2} & -\frac{1}{\omega_2^2} & 0 & 0 \end{bmatrix} \tag{127}$$

where

$$\omega_1 = \sqrt{\frac{k_1}{m_1}} \quad ; \quad \omega_2 = \sqrt{\frac{k_2}{m_2}} \quad ; \quad \epsilon = \frac{m_2}{m_1} \quad ; \quad \zeta = \frac{c}{2\sqrt{m_1 k_1}} \tag{128}$$

Using the condition

$$\left[U\right] - \frac{1}{\alpha}\left[I\right] = \begin{bmatrix} -\frac{1}{\alpha} & 0 & 1 & 0 \\ 0 & -\frac{1}{\alpha} & 0 & 1 \\ -\frac{1}{\omega_1^2} - \frac{1}{\epsilon}\frac{1}{\omega_2^2} & -\frac{1}{\omega_2^2} & -\frac{2\zeta}{\omega_1} - \frac{1}{\alpha} & \frac{2\zeta}{\omega_1} \\ -\frac{1}{\epsilon}\frac{1}{\omega_2^2} & -\frac{1}{\omega_2^2} & 0 & -\frac{1}{\alpha} \end{bmatrix} = 0 \tag{129}$$

and expanding this matrix in cofactors of the first row yields

$$\alpha^4 + 2\zeta\omega_1 \left(1 + \frac{1}{\epsilon}\right) \alpha^3 + \left(\omega_1^2 + \omega_2^2 + \frac{1}{\epsilon}\,\omega_1^2\right) \alpha^2 + 2\zeta\omega_1\omega_2^2\,\alpha + \omega_1^2\omega_2^2 = 0 \qquad (130)$$

Solution of this equation may be obtained by use of the Test-Function Method for determining the roots of an algebraic equation (25). To find the eigenvectors, one can make use of the fact that they are proportional to the cofactors of any row of the matrix of Eq. (129). Thus, one obtains for the third row

$$\left\{\phi^n\right\} = \begin{Bmatrix} \alpha_n \begin{Bmatrix} -\dfrac{1}{\alpha_n}\left(\dfrac{1}{\alpha_n^2} + \dfrac{1}{\omega_2^2}\right) \\ \dfrac{1}{\alpha_n}\,\dfrac{1}{\epsilon\omega_2^2} \end{Bmatrix} \\ \\ \begin{Bmatrix} -\dfrac{1}{\alpha_n}\left(\dfrac{1}{\alpha_n^2} + \dfrac{1}{\omega_2^2}\right) \\ \dfrac{1}{\alpha_n}\,\dfrac{1}{\epsilon\omega_2^2} \end{Bmatrix} \end{Bmatrix} = \begin{Bmatrix} \alpha_n \left\{\phi^n\right\} \\ \\ \left\{\phi^n\right\} \end{Bmatrix} \qquad (131)$$

Having found the α's and Φ's, the solutions of Eqs. (120) and (121) may be determined as follows

$$x_i(t) = \sum_{n=1}^{4} \phi_i^n \frac{1}{R_n} \int_0^t e^{\alpha_n(t-\tau)} F_n(\tau)\, d\tau \qquad (132)$$

where R_n is defined by Eq. (101) and

$$F_n(\tau) = \left\{\phi^n\right\}^T \left\{f(\tau)\right\} \qquad (133)$$

Similarly

$$y_i(t) = \sum_{n=1}^{4} \phi_i^n \frac{1}{R_n} \int_0^t e^{\alpha_n(t-\tau)} G_n(\tau)\, d\tau \qquad (134)$$

where

$$G_n(\ ) = \left\{\phi^n\right\}^T \left\{g(\tau)\right\} = k_1 \left(\phi_2^n - \phi_1^n\right) \left(x_1^3 - 3x_1^2 x_2^2 + 3x_1 x_2^2 - x_1^3\right) \qquad (135)$$

To determine the statistical moments of the output, assume first that the shape of the runway is a stationary Gaussian process with zero mean value whose autocorrelation function is $\psi(\Delta s) = \psi(o)\,\delta(\Delta s)$, $\psi(o)$ being the mean square value of the profile and δ is the Dirac Delta Function. In such cases, using Eqs. (132) and (133) gives

$$\langle x_1(t)x_1(t+\tau)\rangle = \sum_{n=1}^{4}\sum_{m=1}^{4} \frac{1}{R_n R_m}\,\phi_1^n\phi_1^m \int_0^t\int_0^{t+\tau} e^{\alpha_n(t-\tau_1)}\, e^{\alpha_m(t+\tau-\tau_2)}\,\phi_2^n\phi_2^m$$

$$= k_2^2\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \phi_1^n\phi_1^m\phi_2^n\phi_2^m \int_0^t\int_0^{t+\tau} e^{\alpha_n(t-\tau_1)}\, e^{\alpha_m(t+\tau-\tau_2)}\,\delta(\tau_2-\tau_1)\, d\tau_1 d\tau_2$$

Integrating with respect to τ_2 first gives

$$\langle x_1(t)x_1(t+\tau)\rangle = k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \phi_1^n\phi_1^m\phi_2^n\phi_2^m \frac{1}{R_n R_m}\int_0^t e^{\alpha_n(t-\tau)}\, e^{\alpha_m(t+\tau-\tau_1)}\, d\tau_1$$

$$= k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \phi_1^n\phi_1^m\phi_2^n\phi_2^m \frac{1}{R_n R_m}\, e^{(\alpha_n+\alpha_m)t}\, e^{\alpha_m\tau}\, \frac{1}{\alpha_n+\alpha_m}\left(1-e^{-(\alpha_n+\alpha_m)t}\right) \qquad (136)$$

The steady state value is now obtained by letting t approach infinity. Thus,

$$\lim_{t\to\infty} \langle x_1(t)x_1(t+\tau)\rangle = -k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \frac{1}{R_n R_m}\,\phi_1^n\phi_1^m\phi_2^n\phi_2^m \frac{1}{\alpha_n+\alpha_m}\, e^{\alpha_m\tau}\ ;\ \tau\geq 0 \qquad (137)$$

Note that for a stable system α_n must be real and negative or complex with a negative real part. Similarly,

$$\lim_{t\to\infty} \langle x_2(t)x_2(t+\tau)\rangle = -k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \frac{1}{R_n R_m}\,\phi_2^n\phi_2^m\phi_2^n\phi_2^m \frac{1}{\alpha_n+\alpha_m}\, e^{\alpha_m\tau}\ ;\ \tau\geq 0 \qquad (138)$$

$$\lim_{t\to\infty} \langle x_1(t)x_2(t+\tau)\rangle = -k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \frac{1}{R_n R_m}\,\phi_1^n\phi_2^m\phi_2^n\phi_2^m \frac{1}{\alpha_n+\alpha_m}\, e^{\alpha_m\tau}\ ;\ \tau\geq 0 \qquad (139)$$

$$\lim_{t\to\infty} \langle x_1(t)x_2(t+\tau)\rangle = -k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4} \frac{1}{R_n R_m}\,\phi_1^n\phi_2^m\phi_2^n\phi_2^m \frac{1}{\alpha_n+\alpha_m}\, e^{-\alpha_n\tau}\ ;\ \tau\leq 0 \qquad (140)$$

The mean square of the output $\{z_i\}$ correct to the first order in κ, is

$$< z_i^2 > = < x_i^2 > + 2 \ < x_i y_i > \qquad ; \quad i=1,2 \tag{141}$$

To find $< x_i y_i >$ for i=1,2 using Eqs. (134) and (135) yields the relation

$$\begin{aligned}
< x_1(t)y_1(t) > &= \sum_{n=1}^{4} \frac{1}{R_n} \phi_1^n \int_0^t e^{\alpha_n(t-\tau)} <x_1(t)G_n(\tau) > d\tau \\
&= k_1 \sum_{n=1}^{2N} \frac{1}{R_n} \phi_1^n (\phi_2^n - \phi_1^n) \int_0^t e^{\alpha_n(t-\tau)} <x_1(t)x_1^3(\tau) > d\tau \\
&- 3k_1 \sum_{n=1}^{2N} \frac{1}{R_n} \phi_1^n (\phi_2^n - \phi_1^n) \int_0^t e^{\alpha_n(t-\tau)} < x_1(t)x_1^2(\tau)x_2(\tau) > d\tau \\
&+ 3k_1 \sum_{n=1}^{2N} \frac{1}{R_n} \phi_1^n (\phi_2^n - \phi_1^n) \int_0^t e^{\alpha_n(t-\tau)} < x_1(t)x_1(\tau)x_2^2(\tau) > d\tau \\
&- k_1 \sum_{n=1}^{2N} \frac{1}{R_n} \phi_1^n (\phi_2^n - \phi_1^n) \int_0^t e^{\alpha_n(t-\tau)} < x_1(t)x_2^3(\tau) > d\tau
\end{aligned} \tag{142}$$

Considering $x_1(t)$, $x_2(t)$, $x_1(\tau)$, $x_2(\tau)$ as a multivariate normal process with zero mean values (22), one obtains

$$\begin{aligned}
<x_1(t)x_1^3(\tau) > &= 3 <x_1^2(\tau)> <x_1(t)x_1(\tau)> \\
<x_1(t)x_1^2(\tau)x_2(\tau)> &= 2 <x_1(t)x_1(\tau)> \ <x_1(\tau)x_2(\tau)> \ + \ <x_1(t)x_2(\tau)> <x_1^2(\tau)> \\
<x_1(t)x_1(\tau)x_2^2(\tau)> &= 2 <x_1(t)x_2(\tau)> \ <x_1(\tau)x_2(\tau)> \\
<x_1(t)x_2^3(\tau)> &= 3 <x_2^2(\tau)> <x_1(t)x_2(\tau)>
\end{aligned} \tag{143}$$

Substituting Eq.(143) into Eq. (142), gives

$$\begin{aligned}
<x_1(t)y_1(t)> \ &= 3k_1<(<x_1^2> + <x_2^2> - 2 <x_1x_2>) \sum_{k=1}^{4} \frac{1}{R_k} \phi_1^k (\phi_2^k - \phi_1^k) \\
&\int_0^t e^{\alpha_k(t-\tau)} (< x_1(t)x_1(\tau)> \ - < x_1(t)x_2(\tau)>) \ d\tau
\end{aligned} \tag{144}$$

Now using the relationships Eq. (137) and (140), Eq. (144) becomes

$$\langle x_1(t)y_1(t)\rangle = 3k_1\left(\langle x_1^2\rangle + \langle x_2^2\rangle - 2\langle x_1x_2\rangle\right)\sum_{k=1}^{4}\frac{1}{R_k}\phi_1^k\left(\phi_2^k - \phi_1^k\right)\int_0^t e^{\alpha_k(t-\tau)}$$

$$k_2^2\,\psi(0)\sum_{n=1}^{4}\sum_{m=1}^{4}\frac{1}{R_nR_m}\phi_1^n\left(\phi_2^m - \phi_1^m\right)\phi_2^n\phi_2^m\frac{1}{\alpha_n+\alpha_m}e^{-\alpha_k(\tau-t)}\,d\tau \tag{145}$$

Performing the integration and letting t approach infinity leads to the expression

$$\lim_{t\to\infty}\langle x_1(t)y_1(t)\rangle = 3k_1\left(\langle x_1^2\rangle + \langle x_2^2\rangle - 2\langle x_1x_2\rangle\right)k_2^2\,\psi(0)\sum_{k=1}^{4}\frac{1}{R_k}\phi_1^k\left(\phi_2^k - \phi_1^k\right)$$

$$\sum_{n=1}^{4}\sum_{m=1}^{4}\frac{1}{R_nR_m}\phi_1^n\phi_2^n\phi_2^m\left(\phi_1^m - \phi_2^m\right)\frac{1}{\alpha_n+\alpha_m}\frac{1}{\alpha_n+\alpha_k} \tag{146}$$

Similarly

$$\lim_{t\to\infty}\langle x_2(t)y_2(t)\rangle = 3k_1\left(\langle x_1^2\rangle + \langle x_2^2\rangle - 2\langle x_1x_2\rangle\right)k_2^2\,\psi(0)\sum_{k=1}^{4}\frac{1}{R_k}\phi_1^k\left(\phi_2^k - \phi_1^k\right)$$

$$\sum_{n=1}^{4}\sum_{m=1}^{4}\frac{1}{R_nR_m}\phi_2^n\phi_2^n\phi_2^m\left(\phi_1^m - \phi_2^m\right)\frac{1}{\alpha_n+\alpha_m}\frac{1}{\alpha_n+\alpha_k} \tag{147}$$

The mean square values of z_1 and z_2 may be obtained from Eq. (141). Suppose now that

$m_1 = 955$ lb-s^2/in

$m_2 = 12$ lb-s^2/in

$c = 1500$ lb-s^2/in

$k_1 = 187{,}500.0$ lb/in

$k_2 = 96000.0$ lb/in

$\varepsilon = 0.15$

$\psi(0) = 0.0475$ in^2

one obtains the following ensemble averages

$\langle x_1^2\rangle = 8.75$ in^2

$\langle x_2^2\rangle = 4.02$ in^2

$\langle x_1y_1\rangle = 22.2$ in^2

$$\langle x_2 y_2 \rangle = 12.3 \text{ in}^2$$
$$\langle z_1^2 \rangle = \underline{\underline{15.40 \text{ in}^2}}$$
$$\langle z_2^2 \rangle = \underline{\underline{7.71 \text{ in}^2}}$$

Take now as a second example, the same system with the autocorrelation function of the runway

$$\psi(\Delta s) = \psi(0) e^{-\eta|\Delta s|} \tag{148}$$

In this case

$$\langle x_1(t) x_1(t+\tau) \rangle = k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_1^n \phi_1^m \phi_2^n \phi_2^m \int_0^t \int_0^{t+\tau} e^{\alpha_m (t-\tau_2)} e^{\alpha_n (t-\tau_1)} e^{-\eta v |\tau_2 - \tau_1|} d\tau_1 d\tau_2 \tag{149}$$

integrating the double integral with respect to τ_2 first, one obtains

$$\langle x_1(t) x_1(t+\tau) \rangle = k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_1^n \phi_1^m \phi_2^n \phi_2^m \left[\int_0^t \int_0^{\tau_1} e^{\alpha_n (t-\tau_1)} e^{\alpha_m (t+\tau-\tau_2)} e^{\eta v (\tau_2 - \tau_1)} d\tau_1 d\tau_2 + \int_0^t \int_{\tau_1}^{t+\tau} e^{\alpha_n (t-\tau_1)} e^{\alpha_m (t+\tau-\tau_2)} e^{-\eta v (\tau_2 - \tau_1)} d\tau_1 d\tau_2 \right]$$

$$= k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_1^n \phi_1^m \phi_2^n \phi_2^m A_{nm}(\tau) \tag{150}$$

Similarly

$$\langle x_2(t) x_2(t+\tau) \rangle = k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_2^n \phi_2^m \phi_2^n \phi_2^m A_{nm}(\tau) \quad ; \tau \geq 0 \tag{151}$$

$$\langle x_1(t) x_2(t+\tau) \rangle = k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_1^n \phi_2^m \phi_2^n \phi_2^m A_{nm}(\tau) \quad ; \tau \geq 0 \tag{152}$$

$$\langle x_1(t) x_2(t+\tau) \rangle = k_2^2 \psi(0) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m} \phi_1^n \phi_2^m \phi_2^n \phi_2^m A_{mn}(-\tau) \quad ; \tau \leq 0 \tag{153}$$

where

$$A_{nm}(\tau) = \frac{e^{-\eta v \tau}}{(\alpha_m + \eta v)(\alpha_n - \eta v)} + \frac{2\eta v\, e^{\alpha_m \tau}}{(\alpha_n + \alpha_m)(\alpha_m^2 - \eta^2 v^2)} \tag{154}$$

Following the same argument as in the previous example,

$$\langle x_1(t) y_1(t) \rangle = 3k_1 \left(\langle x_1^2 \rangle + \langle x_2^2 \rangle - 2\langle x_1 x_2 \rangle\right) \sum_{k=1}^{4} \frac{1}{R_k} \phi_1^k \left(\phi_2^k - \phi_1^k\right)$$

$$\int_0^t e^{\alpha_k (t-\tau)} \left(\langle x_1(t) x_1(\tau) \rangle - \langle x_1(t) x_2(\tau) \rangle\right) d\tau \tag{155}$$

Substituting now the values of $\langle x_1(t) x_1(\tau) \rangle$ and $\langle x_1(t) x_2(\tau) \rangle$ into this equation and carrying out the integration, one obtains, after letting t approach infinity,

$$\langle x_1(t) y_1(t) \rangle = 3k_1 \left(\langle x_1^2 \rangle + \langle x_2^2 \rangle - 2\langle x_1 x_2 \rangle\right) k_2^2\, \psi(0) \sum_{k=1}^{4} \frac{1}{R_k} \phi_1^k \left(\phi_1^k - \phi_2^k\right) \sum_{n=1}^{4} \sum_{m=1}^{4} \frac{1}{R_n R_m}$$

$$\phi_1^n \left(\phi_1^m - \phi_2^m\right) \phi_2^n \phi_2^m\, B_{knm} \tag{156}$$

Similarly

$$\langle x_2(t) y_2(t) \rangle = 3k_1 \left(\langle x_1^2 \rangle + \langle x_2^2 \rangle - 2\langle x_1 x_2 \rangle\right) k_2^2\, \psi(0) \sum_{k=1}^{4} \frac{1}{R_k} \phi_2^k \left(\phi_1^k - \phi_2^k\right) \sum_{n=1}^{4} \sum_{m=1}^{4}$$

$$\frac{1}{R_n R_m} \phi_2^n \left(\phi_1^m - \phi_2^m\right) \phi_2^n \phi_2^m\, B_{knm} \tag{157}$$

where

$$B_{knm} = \frac{1}{(\alpha_n + \eta v)(\alpha_k - \eta v)(\alpha_m - \eta v)} + \frac{2\eta v}{(\alpha_n + \alpha_k)(\alpha_n + \alpha_m)(\alpha_n^2 - \eta^2 v^2)}$$

Substituting the same numerical values of the system as given in the previous example and taking

$\eta =$ 0.00179 1/in.

$v =$ 1200.0 in/s

$\psi(0) =$ 0.475 in^2

one obtains

$\langle x_1^2 \rangle =$ 5.75 in^2

$\langle x_2^2 \rangle = 2.64 \text{ in}^2$

$\langle x_1 y_1 \rangle = 5.28 \text{ in}^2$

$\langle x_2 y_2 \rangle = 3.18 \text{ in}^2$

$\langle z_1^2 \rangle = \underline{\underline{7.34 \text{ in}^2}}$

$\langle z_2^2 \rangle = \underline{\underline{3.60 \text{ in}^2}}$

Equivalent Linearization Method (29)

The method of equivalent linearization is an extension of the procedure of Krilov and Bojolinbov for deterministic analysis of slightly nonlinear systems. To illustrate this method consider the following system subjected to a stationary Gaussian excitation

$$\ddot{x} + \beta\dot{x} + \omega_0^2 (x + \kappa g (x,\dot{x})) = f(t) \tag{158}$$

where both β and κ are small in some sense such that the system is lightly damped and weakly nonlinear. Now consider the following equation

$$\ddot{x} + \beta_{eq}\dot{x} + \omega_{eq}^2 + e(x,\dot{x}) = f(t) \tag{159}$$

where β_{eq} is the equivalent linear damping coefficient per unit mass, ω_{eq}^2 is the equivalent linear stiffness coefficient per unit mass and e is an error term The equivalent linearization method as presented by Caughey selects values of β_{eq} and ω_{eq}^2 which force the mean square value of the error to be a minimum. Thus, from the above equation

$$e(x,\dot{x}) = (\beta-\beta_{eq})\, x + (\omega_0^2-\omega_{eq}^2)\, x + \kappa\, \omega_0^2 g(x,\dot{x}) \tag{160}$$

and

$$\frac{\partial\langle e^2\rangle}{\partial\omega_{eq}^2} = 0 \quad ; \quad \frac{\partial\langle e^2\rangle}{\partial\beta_{eq}} = 0$$

giving

$$\langle(\omega_0^2 - \omega_{eq}^2)\, x^2 + \kappa\omega_0^2\, xg(x,\dot{x})\rangle = 0 \tag{161}$$

$$<(\beta - \beta_{eq})\,\dot{x}^2 + \kappa\omega_0^2\,\dot{x}\,g(x,x)> = 0 \tag{162}$$

where use has been made of the fact that the process is stationary; therefore $<x\dot{x}> = 0$. Thus, one obtains

$$\beta_{eq} = \beta + \kappa\omega_0^2 <\dot{x}g(x,\dot{x})>/<\dot{x}^2> \tag{163}$$

$$\omega_{eq}^2 = \omega_0^2 + \kappa\omega_0^2 <xg(x,\dot{x})>/<x^2> \tag{164}$$

If e is neglected in Eq. (159), the response will be Gaussian. Thus,

$$p(x,\dot{x}) = \frac{1}{2\pi\sqrt{<x^2><\dot{x}^2>}}\ \exp\left[-\frac{1}{2}\left(\frac{x^2}{<x^2>} + \frac{\dot{x}^2}{<\dot{x}^2>}\right)\right] \tag{165}$$

after taking into account the fact that $<x\dot{x}> = 0$. It is now possible to evaluate $<xg(x,\dot{x})>$ and $<\dot{x}g(x,\dot{x})>$ in terms of $<x^2>$ and $<\dot{x}^2>$ and the mean square response of the equivalent linear system can be expressed as

$$<x^2> = \int_0^\infty \frac{S_f(\omega)\,d\omega}{(\omega_{eq}^2-\omega^2)^2 + (\omega\beta_{eq})^2} \quad ; \quad <\dot{x}^2> = \int_0^\infty \frac{\omega^2 S_f(\omega)\,d\omega}{(\omega_{eq}^2-\omega^2)^2 + (\omega\beta_{eq})^2} \tag{166}$$

Substituting β_{eq} and ω_{eq}^2 as given by Eqs. (163) and (164) into Eq. (166) enables one to determine the mean square responses. Consider now the example given in Section 1, that is, take $g(x,\dot{x}) = x^3$, one can state that

$$<\dot{x}g(x)> = \int_0^\infty\int_0^\infty \dot{x}x^3\,p(x,\dot{x})\,dxd\dot{x} = 0 \tag{167}$$

$$<xg(x)> = \int_0^\infty x^4\,p(x)dx = 3\,<x^2>^2 \tag{168}$$

Thus,

$$\beta_{eq} = \beta \tag{169}$$

and

$$\omega_{eq}^2 = \omega_0^2 + 3\omega_0^2\,\kappa\,<x^2> \tag{170}$$

If the system is subjected to white noise excitation whose power spectral density function is $S_f(\omega) = S_o$,

$$\langle x^2 \rangle = \frac{\pi}{2} \frac{S_0}{\beta_{eq}\omega_{eq}^2} = \frac{\pi}{2} \frac{S_0}{\beta\omega^2} (1 + 3 \langle x^2 \rangle)^{-1} = \sigma_x^2 (1 + 3 \langle x^2 \rangle)^{-1} \tag{171}$$

where σ_x^2 is the mean square of x if $g(x) = 0$ and

$$\langle x^2 \rangle = \frac{\pi S_0}{2\beta_{eq}} = \frac{\pi S_0}{2\beta} \tag{172}$$

Solving for $\langle x^2 \rangle$ using Eq. (171) gives the relation

$$\langle x^2 \rangle = \frac{1}{6\kappa} \left(\sqrt{1 + 12\kappa\, \sigma_x^2} - 1\right) \tag{173}$$

considering only the positive root. Expanding the term $\sqrt{1 + 12\kappa\, \sigma_x^2}$, one obtains the relation

$$\langle x^2 \rangle \doteq \sigma_x^2 - 3\kappa\, \sigma_x^4$$

which agrees with the result obtained by the perturbation technique.

Discussion

From the above presentation of the two approximate methods, the perturbation method and the equivalent linearization method, it is apparent that each method has its advantages and disadvantages in handling the airplane problem of concern to us herein. The perturbation method, although applicable to problems having nonlinearities which involve both displacements and velocities, is restricted to cases in which the nonlinearities can be expressed in terms of polynomials. Although the spring forces in the landing gear systems can be approximated by polynomials, the damping forces and the Coulomb friction forces cannot be represented in that manner These nonlinear forces, however, can be handled by the equivalent linearization method. For instance, for the system whose equation of motion is

$$\ddot{x} + \gamma\dot{x}^2 \operatorname{sgn} \dot{x} + \omega_0^2 x = f(t) \tag{174}$$

one only needs to consider the equation

$$\ddot{x} + \beta_{eq}\dot{x} + \omega_0^2 x + e(\dot{x}) = f(t) \tag{175}$$

to see that

$$e(\dot{x}) = \gamma\dot{x}^2 \text{ sgn } \dot{x} - \beta_{eq}\dot{x} \tag{176}$$

and

$$\langle e^2(\dot{x})\rangle = \langle(\gamma\dot{x}^2 \text{ sgn } \dot{x} - \beta_{eq}\dot{x})^2\rangle \tag{177}$$

The condition $\frac{\partial(e^2\langle\dot{x}\rangle)}{\partial\beta_{eq}}$ yields,

$$\langle\gamma\dot{x}^3 \text{ sgn } \dot{x} - \beta_{eq}\dot{x}^2\rangle = 0 \tag{178}$$

or

$$\beta_{eq} = \frac{\langle\gamma\dot{x}^3 \text{ sgn } \dot{x}\rangle}{\langle\dot{x}^2\rangle} \tag{179}$$

Assuming the excitation is stationary Gaussian, the probability density function for $\dot{x}$ of the equivalent linear system is

$$p(\dot{x}) = \frac{1}{2\pi\sqrt{\langle\dot{x}^2\rangle}} \exp\left[-\frac{1}{2}\frac{\dot{x}^2}{\langle\dot{x}^2\rangle}\right] \tag{180}$$

Thus,

$$\langle\gamma\dot{x}^3 \text{ sgn } \dot{x}\rangle = \int_{-\infty}^{\infty}\gamma\dot{x}^3 \text{ sgn } \dot{x}\, p(\dot{x})dx = 2\gamma\int_{-\infty}^{\infty}\dot{x}^3 p(\dot{x})dx = \frac{4\gamma\langle\dot{x}^2\rangle}{\sqrt{2\pi}}\sqrt{\langle\dot{x}^2\rangle} \tag{181}$$

and

$$\beta_{eq} = \frac{4\gamma}{\sqrt{2\pi}}\sqrt{\langle\dot{x}^2\rangle} \tag{182}$$

Now, if the excitation is white noise, for example, one gets the relation

$$\langle x^2\rangle = \frac{\pi}{2}\frac{S_0}{\beta_{eq}} = \frac{\pi S_0\sqrt{2\pi}}{8\gamma\sqrt{\langle\dot{x}^2\rangle}} \tag{183}$$

Therefore,

$$\sqrt{\langle\dot{x}^2\rangle} = \frac{1}{2}\sqrt[6]{\frac{2\pi^3 S_0^{\,2}}{\gamma^2}} \tag{184}$$

Hence,

$$\beta_{eq} = 2\gamma\sqrt[6]{\frac{2\pi^3 S_0^{\,2}}{\gamma^2}} \tag{185}$$

The Coulomb friction force can be equivalently linearized in a similar manner. From the above discussion it is seen that both the damping forces and the Coulomb friction forces in the landing gear systems can be successfully handled by the equivalent linearization method, however, the possibility of extending the equivalent linearization method to the case of multi-degree of freedom systems does not appear to be promising. It is therefore thought that for an engineering solution to the problem we might first use the equivalent linearization method to determine the equivalent linear damping coefficients of the nonlinear damping forces and the Coulomb friction forces for both landing gears considering the airplane as a single-degree-of-freedom system and then use the perturbation method to perturb on the nonlinearity of the spring force in the landing systems considering the system as a multi-degree-of-freedom system. This suggested procedure, of course, neglects certain cross coupling effects which are felt to be small.

IV CONCLUSIONS AND RECOMMENDATIONS

As a result of the general investigation reported herein, the following conclusions have been made:

(1) A method of analysis has been developed and programmed for solution on the IBM 7090 computer which yields the deterministic dynamic response of airplanes during take-off or landing in an effective and efficient manner.

(2) A deterministic dynamic response analysis must be used when predicting peak response caused by such discrete runway unevenness as is present at runway intersections and at locations of excessive runway settlement.

(3) It is necessary that the effects of the lower flexural modes of the free-free airplane be included in a dynamic analysis of any large airplane during take-off or landing, if relatively accurate results are to be obtained.

(4) Complete linearization in idealizing the structural characteristics of large airplanes can lead to appreciable errors in determining dynamic response.

(5) Application of the analysis shows somewhat higher peak response for the 733-94 airplane as compared with the 707 airplane.

(6) A statistical dynamic response analysis using runway unevenness power spectral density functions can be very useful in predicting fatigue life of structural components.

(7) The analytical methods developed for treating statistically certain non-linear systems are considered to have direct application in determining dynamic response of large airplanes during take-off or landing.

In the interest of aiding the SST development program and in aiding future research, the following recommendations are made:

(1) Deterministic dynamic response analyses should be made using the latest SST designs being developed and using runway profiles of the major existing civil airports for the purpose of establishing more complete design criteria for supersonic transports and for the purpose of establishing modifications to the current Federal Aviation Agency runway smoothness specifications, if necessary.

(2) Further study is needed to establish the validity of the statistical methods of analysis reported herein and to further the development of analytical methods in this area.

BIBLIOGRAPHY

1. Houbolt, J. C., PROGRESS AND RECOMMENDED RESEARCH ACTIVITY ON THE RUNWAY ROUGHNESS PROBLEM, Presented at the Structures and Materials Panel, AGARD, Copenhagen, Denmark, Oct. 20-29, 1958.

2. Houbolt, J. C., RUNWAY ROUGHNESS STUDIES IN THE AERONAUTICAL FIELD, Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. ATI, March 1961, pp. 11-31.

3. Plantema, F. J., and Buhrman, J., SOME EXPERIMENTAL INVESTIGATIONS ON RUNWAY WAVINESS, De Ingenieur, Vol. 75, No. 31, August 1963.

4. Thompson, W. E., MEASUREMENTS AND POWER SPECTRA OF RUNWAY ROUGHNESS AT AIRPORTS IN COUNTRIES OF THE NORTH ATLANTIC TREATY ORGANIZATION, NACA TN 4303, 1958.

5. Walls, J. H., Houbolt, J. C., and Press, H., SOME MEASUREMENTS AND POWER SPECTRA OF RUNWAY ROUGHNESS, NACA TN 3305, 1954.

6. Turner, D. F., Brown, R. S., and Snyder, W. H., AUTOMATIC RUNWAY PROFILE MEASURING INSTRUMENTATION AND RUNWAY PROPERTIES, Part I - Equipment. WADD Technical Reporb 60-470, February 1961.

7. Turner, D. F., Brown, R. S., and Patton, P. C., AUTOMATIC RUNWAY PROFILE MEASURING INSTRUMENTATION AND RUNWAY PROPERTIES, Part II - Equipment Trials. WADD Technical Report 60-470, October 1961.

8. Turner, D. F., AUTOMATIC RUNWAY PROFILE MEASURING INSTRUMENTATION AND RUNWAY PROPERTIES, Part III - Base Surveys. WADD TR-60-470, July 1963.

9. Grimes, C. K., DEVELOPMENT OF A METHOD AND INSTRUMENTATION FOR EVALUATION OF RUNWAY ROUGHNESS EFFECTS ON MILITARY AIRCRAFT, NATO.AGARD. Report 119, 1957.

10. Morris, G. J., and Stickle, J. W., RESPONSE OF A LIGHT AIRPLANE TO ROUGHNESS OF UNPAVED RUNWAYS, NASA TN D-510, September 1960.

11. Silby, N. S., AN ANALYTICAL STUDY OF EFFECTS OF SOME AIRPLANE AND LANDING GEAR FACTORS ON THE RESPONSE TO RUNWAY ROUGHNESS WITH APPLICATION TO SUPERSONIC TRANSPORTS, NASA TN D-1492, December 1962.

12 Hall, A. W., and Kopelson, S., THE LOCATION AND SIMULATED REPAIR OF ROUGH AREAS OF A GIVEN RUNWAY BY AN ANALYTICAL METHOD, NASA TN D-1486, October 1962.

13. Houbolt, J. C., Walls, J. H., and Smiley, R. F., ON SPECTRAL ANALYSIS OF RUNWAY ROUGHNESS AND LOADS DEVELOPED DURING TAXIING, NACA TN 3484, 1955

14. McKay, J. M., MEASUREMENTS OF GROUND-REACTION FORCES AND VERTICAL CENTER-OF-GRAVITY ACCELERATIONS OF A BOMBER AIRPLANE TAXIING OVER OBSTACLES, NACA TN 4400, 1958.

15. Milwitzky, B., STUDY OF TAXIING PROBLEMS ASSOCIATED WITH RUNWAY ROUGHNESS, NASA Memo. 2-21-59L, 1959.

16. Ferguson, T. R., Mollick, J., and Kitts, W.W., A RATIONAL METHOD FOR PREDICTING ALIGHTING GEAR DYNAMIC LOADS, Vol. 1, Vol. 2. ASD TD R 62 555. December 1963.

17. Kozin, F., Cote, L. J., and Bogdanoff, J. L., STATISTICAL STUDIES OF STABLE GROUND ROUGHNESS, U.S. Army Tank-Automotive Center, Report No. 8391, November 1963.

18. Bogdanoff, J. L., and Kosin, F., ADDITIONAL RESULTS ON THE STATISTICAL ANALYSIS OF A LINE R VEHICLE USING MEASURED GROUND POWER SPECTRAL DENSITY, U.S. Army Tank-Automotive Center, Report No. 8392, November 1963

19. Milwitzky, B., and Cook, F. E., ANALYSIS OF LANDING GEAR BEHAVIOR, NACA TR 1154, 1953.

20. Crandall, S. H., and Mark, W. D., RANDOM VIBRATION IN MECHANICAL SYSTEMS, Academic Press, New York and London, 1963.

21. Crandall, S. H. (ed.), RANDOM VIBRATION, Technology Press and Wiley, New York, 1963.

22. Middleton, D., AN INTRODUCTION TO STATISTICAL COMMUNICATION THEORY, Mc-Graw-Hill Book Company, Inc., New York, 1960.

23. Minorsky, N., NONLINEAR MECHANICS, J. W. Edward, Ann Arbon, Michigan, 1947.

24. Foss, K., COORDINATES WHICH UNCOUPLE THE EQUATIONS OF MOTION OF DAMPED LINEAR DYNAMIC SYSTEMS, Technical Report 25-20, Massachusetts Institute of Technology, March 1956.

25. Karman, T. V., and Biot, M., MATHEMATICAL METHODS IN ENGINEERING, McGraw-Hill Book Company, Inc., New York and London, 1940.

26. Stumpf, H. J., RESPONSE OF MECHANICAL SYSTEMS TO RANDOM EXCITING FORCES, NOTS TP 2365, NAVORD Report 7010, December 1959.

27. Caughey, T. K., DERIVATION AND APPLICATION OF THE FOKKER-PLANK EQUATION TO DISCRETE NONLINEAR DYNAMIC SYSTEMS SUBJECTED TO WHITE RANDOM EXCITATION, Journal of the Acoustical Society of America, Vol. 35, No. 11, November 1963.

28. Crandall, S. H., PERTURBATION TECHNIQUES FOR RANDOM VIBRATION OF NONLINEAR SYSTEMS, Journal of the Acoustical Society of America, Vol. 35, No. 11, November 1963.

29. Caughey, T. K., EQUIVALENT LINEARIZATION TECHNIQUES, Journal of the Acoustical Society of America, Vol. 35, No. 11, Ncvember, 1963.

30. Morris, G. J., RESPONSE OF A JET TRAINER AIRCRAFT TO ROUGHNESS OF THREE RUNWAYS, NASA TN D-2203, 1964

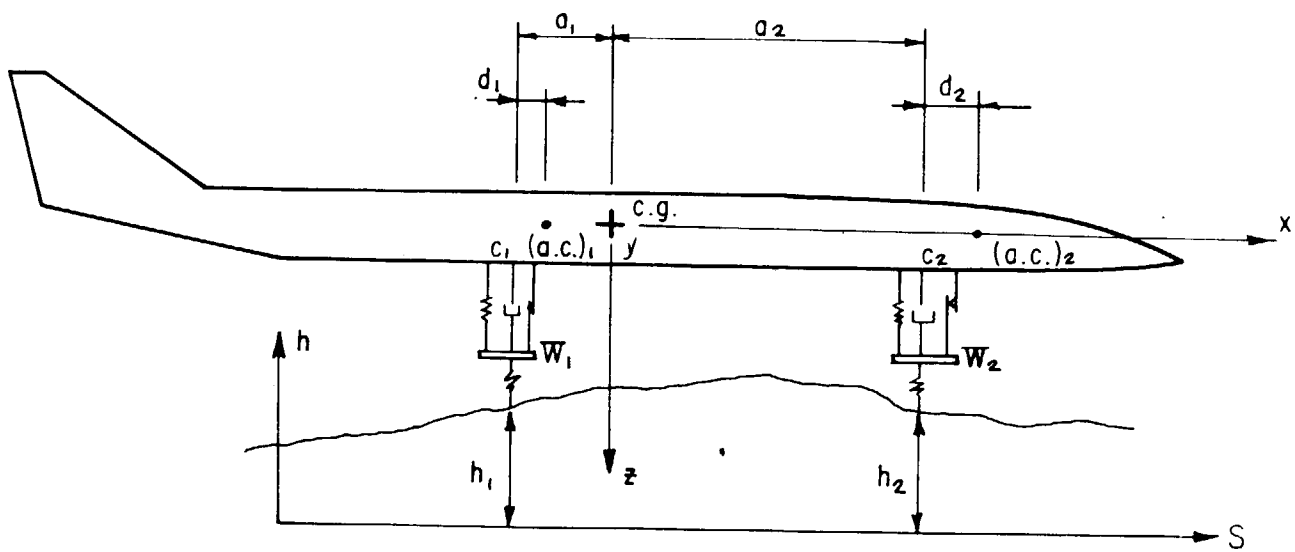


FIG. 1 - MODEL FOR THE AIRCRAFT

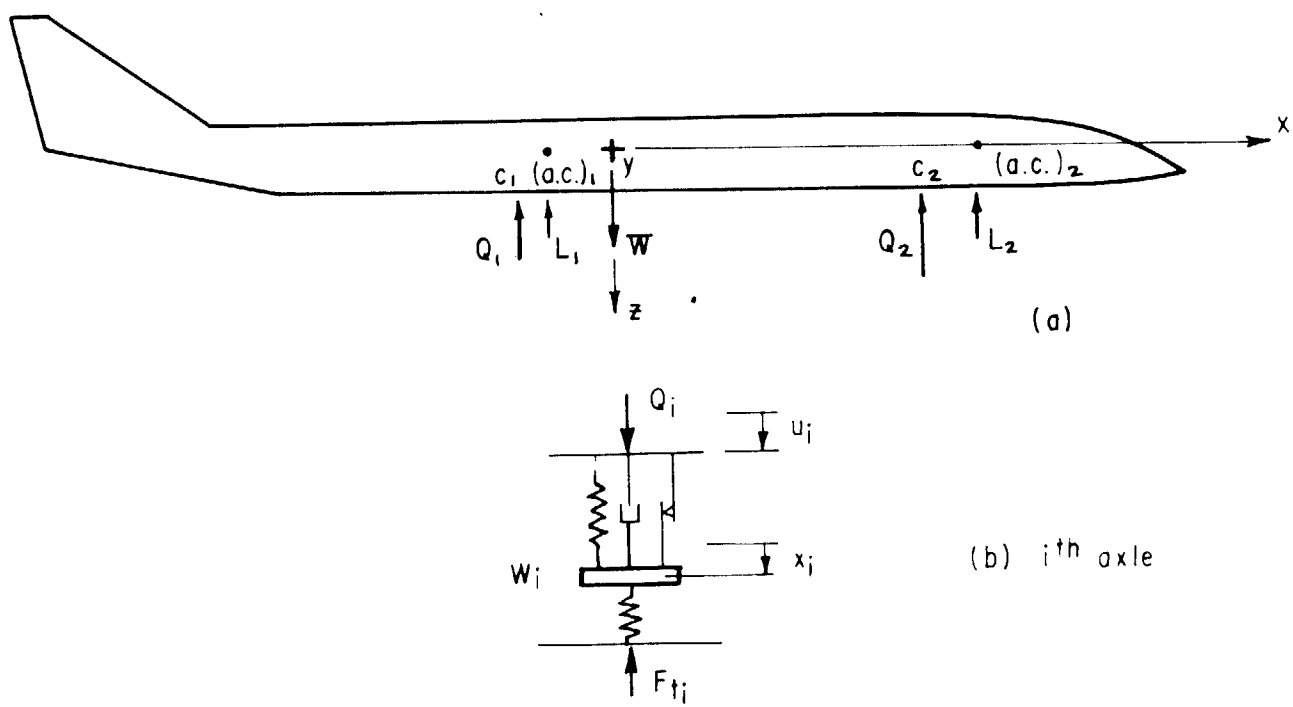
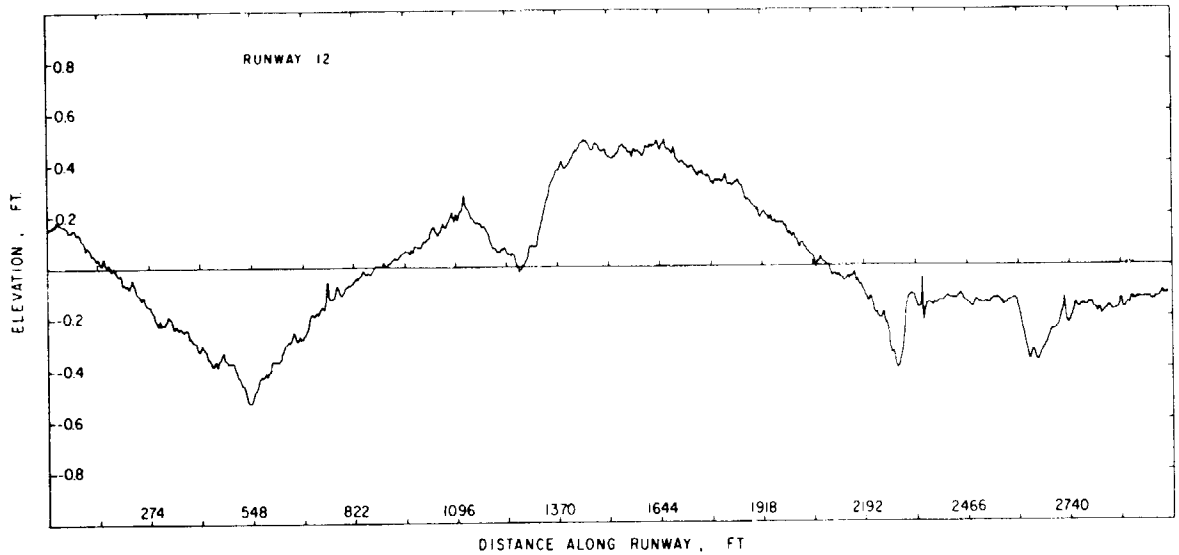


FIG. 2 – FREEBODY DIAGRAM OF AIRFRAME AND UNSPRUNG MASS



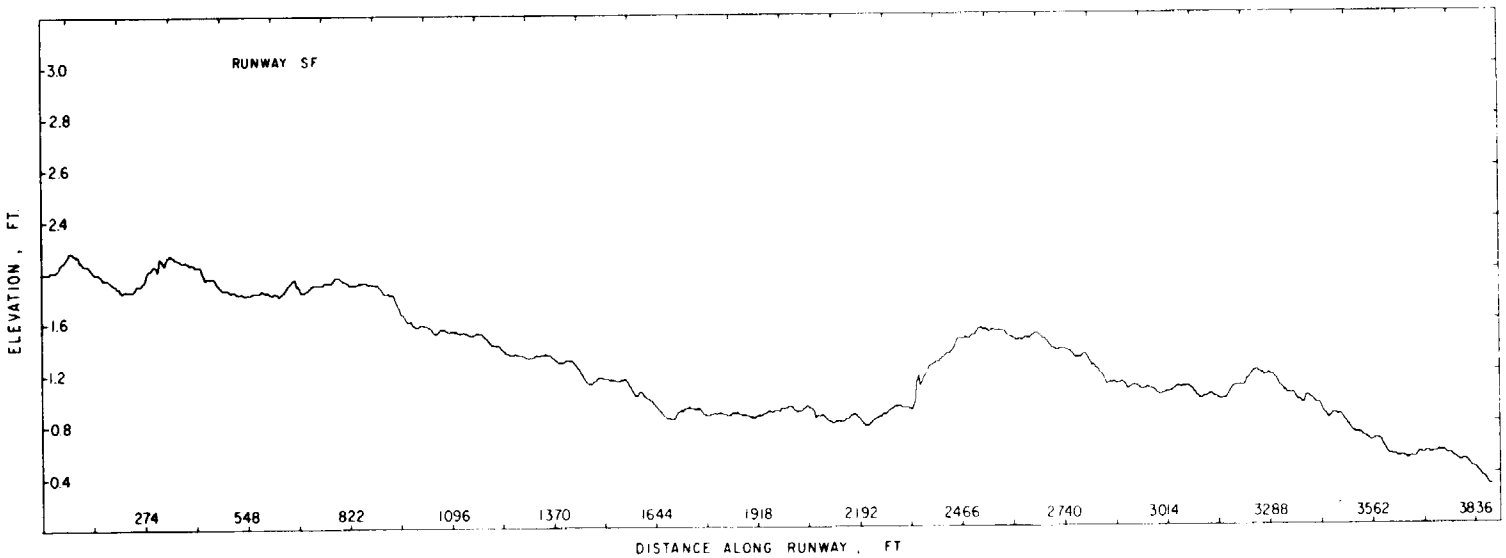


FIG. 3 RUNWAY ELEVATION

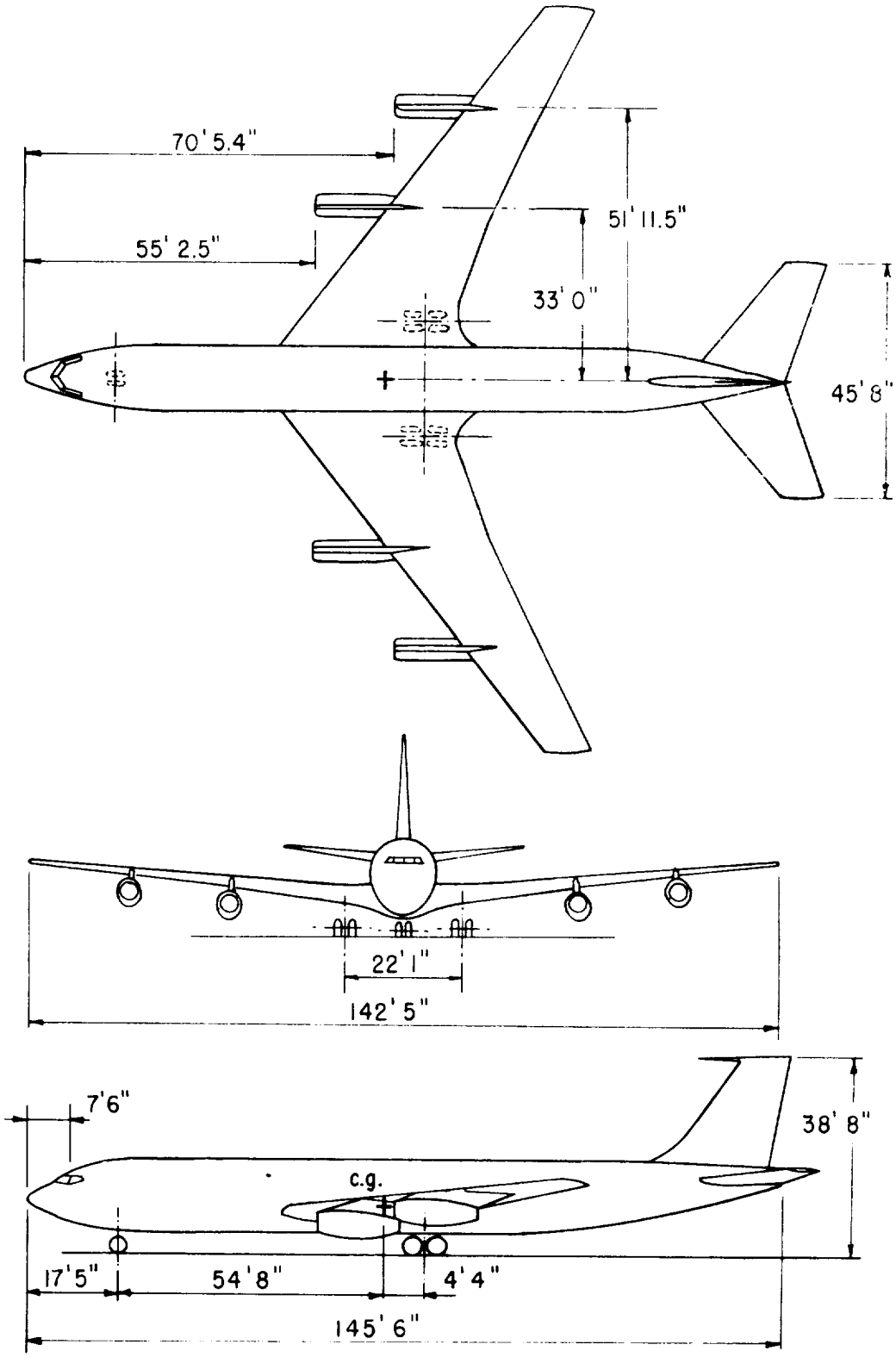
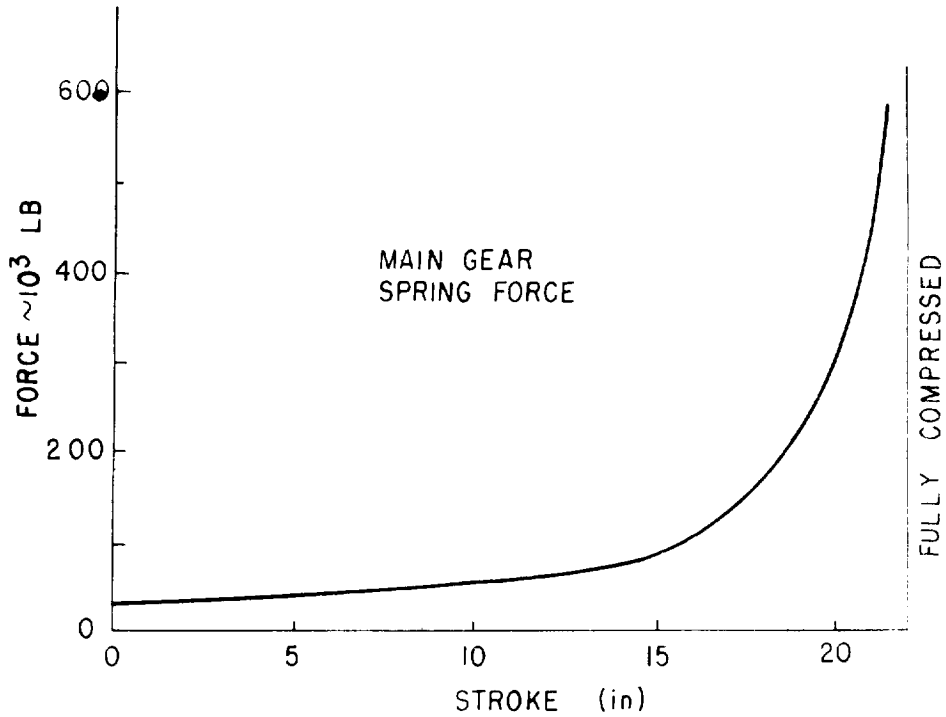


FIG. 4 - GENERAL ARRANGEMENT - BOEING 707



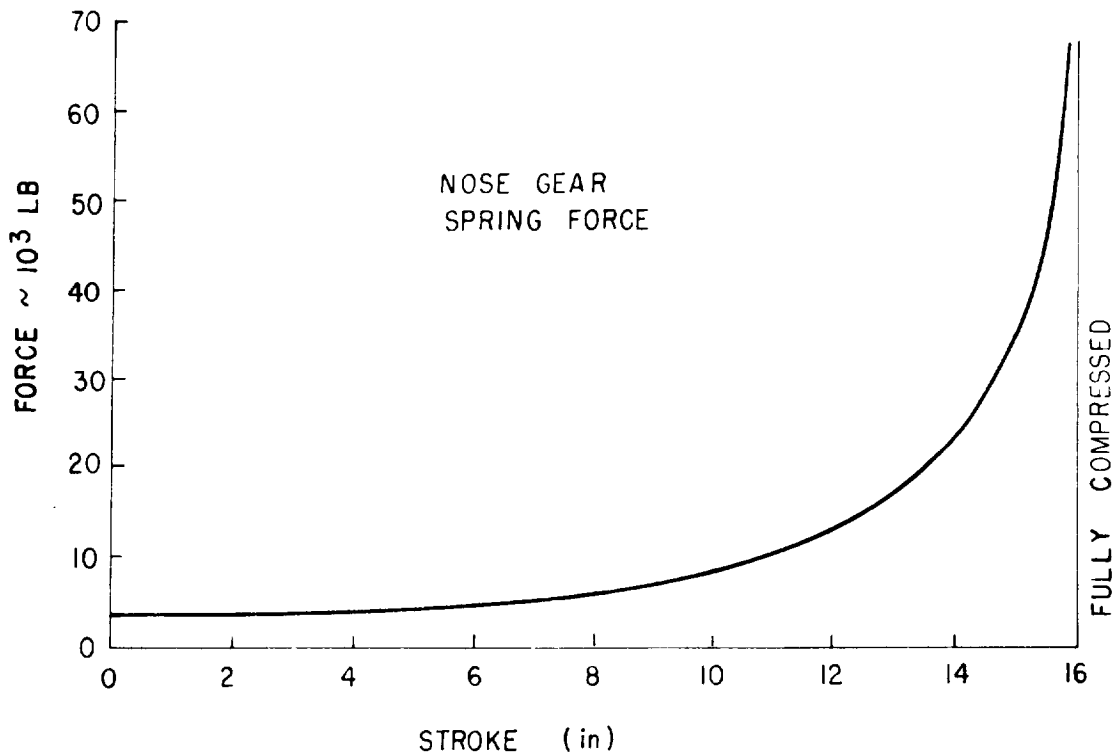
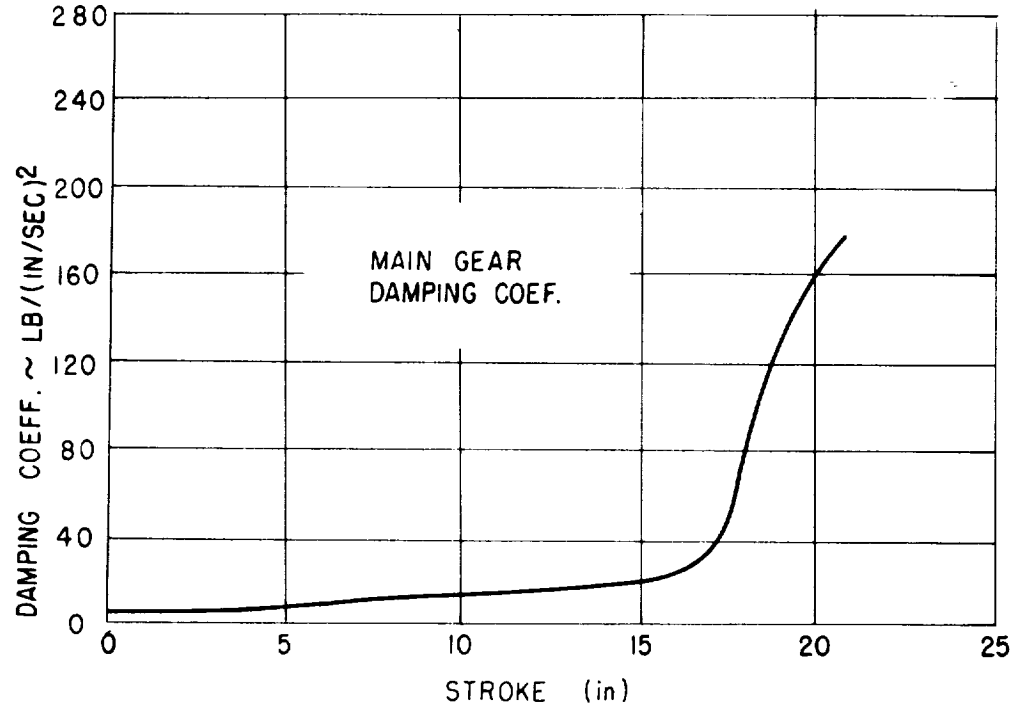


FIG. 5 - LANDING GEAR FORCES - BOEING 707



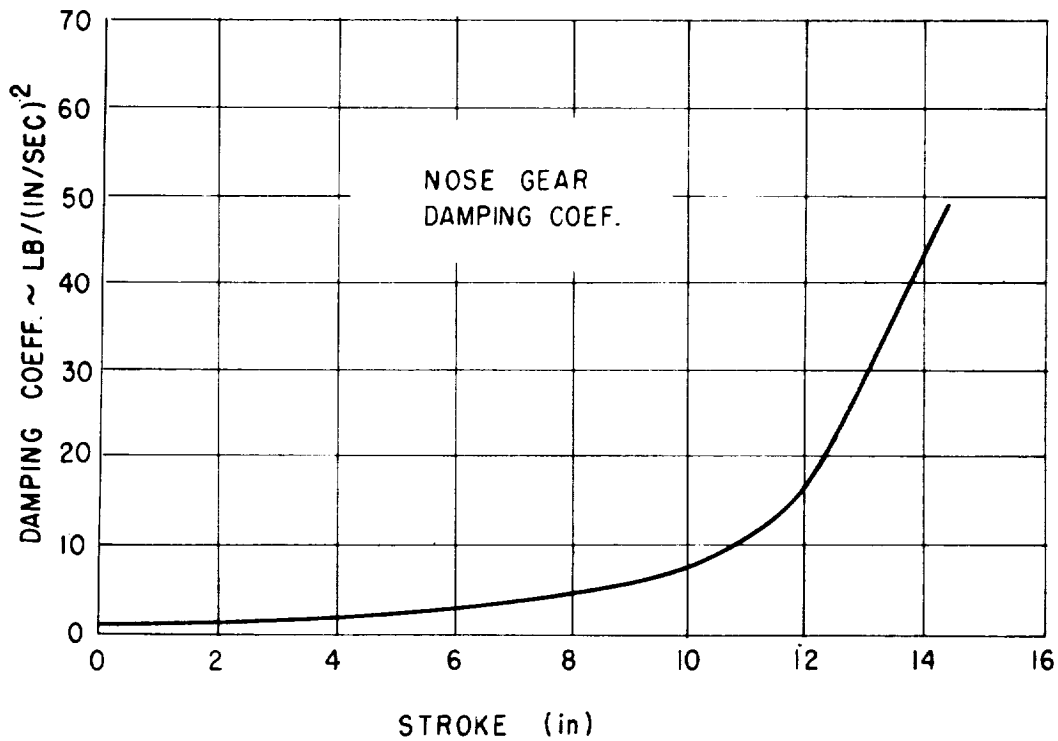


FIG. 6 - LANDING GEAR DAMPING COEFFICIENTS
BOEING 707

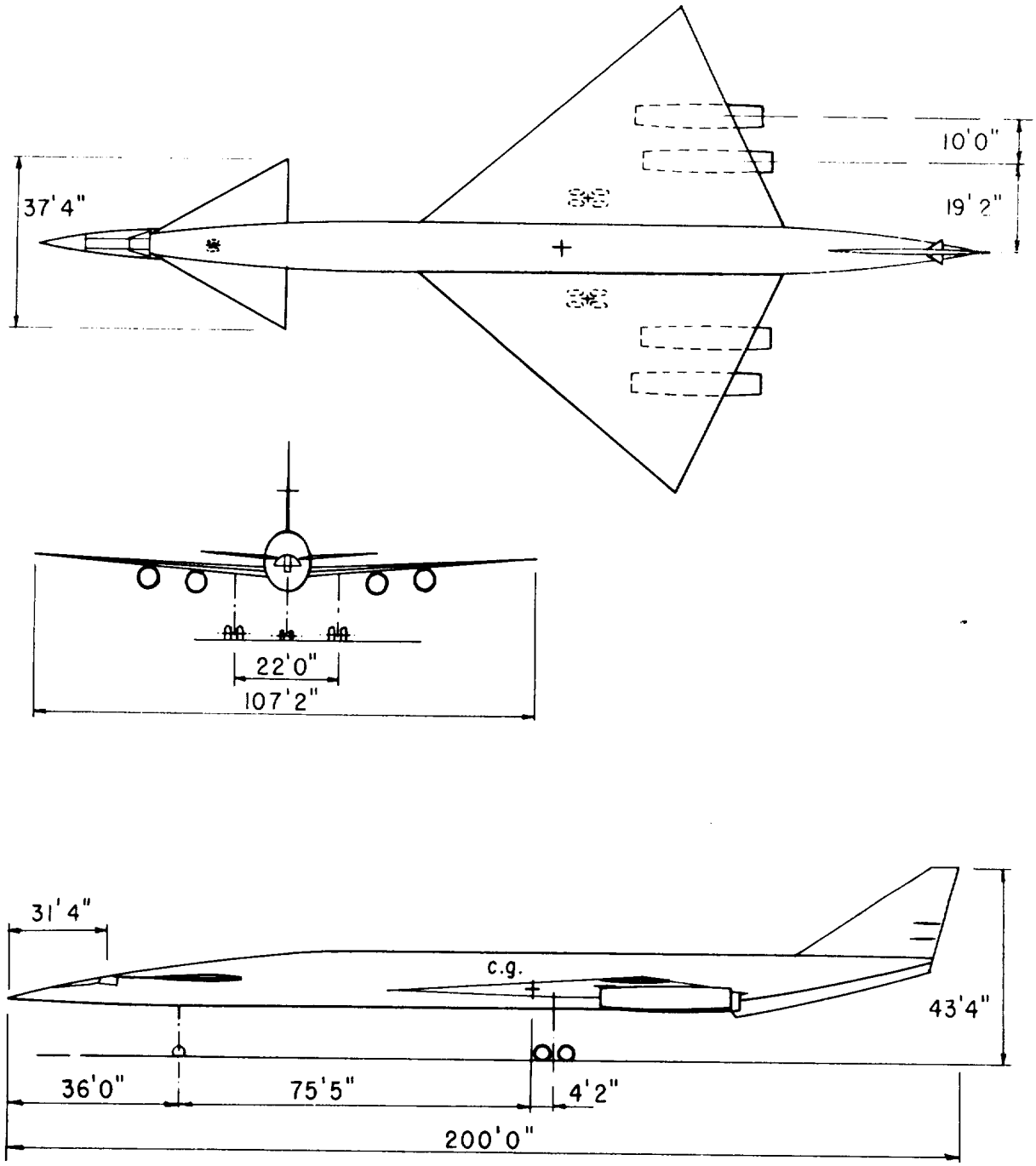
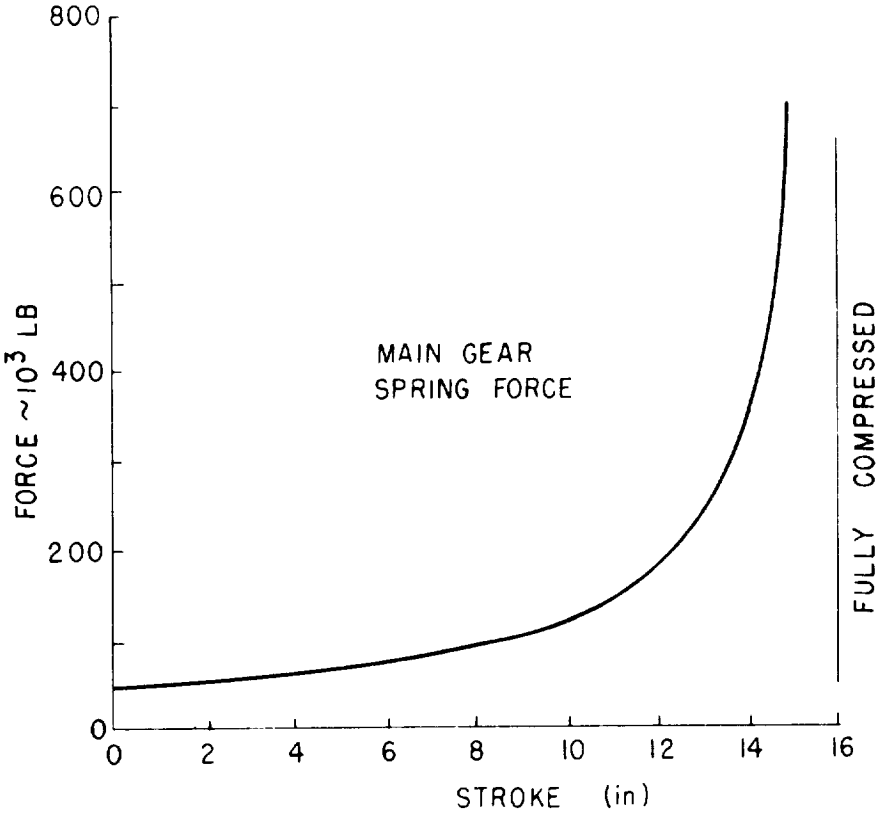


FIG. 7 - GENERAL ARRANGEMENT - BOEING 733 94



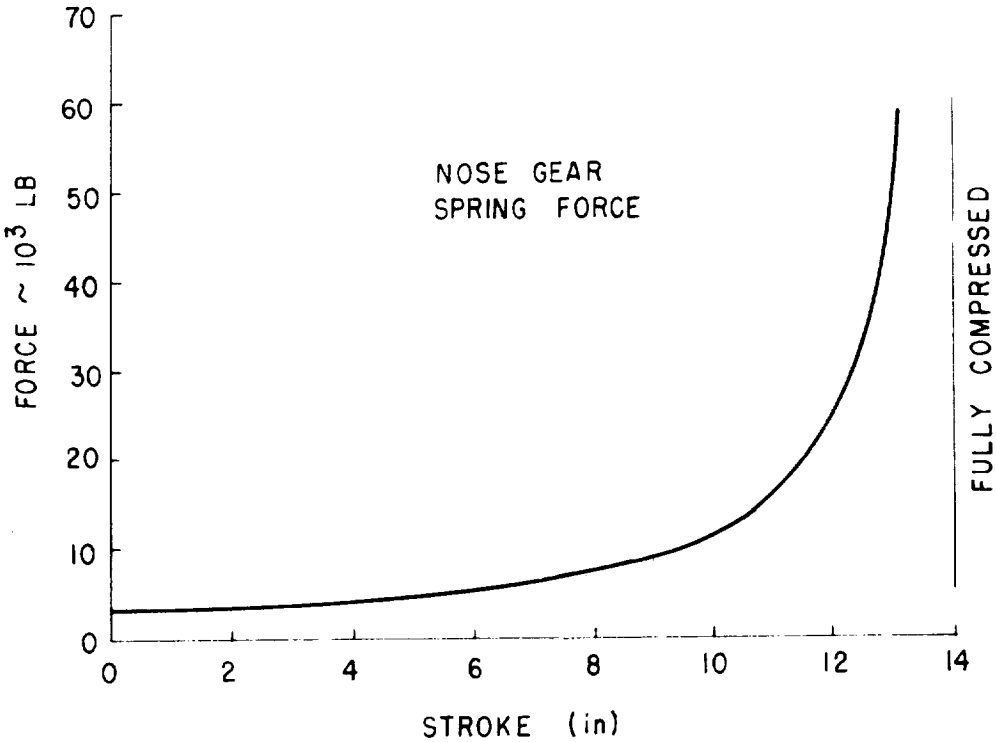


FIG. 8 - LANDING GEAR FORCES - BOEING 733 94

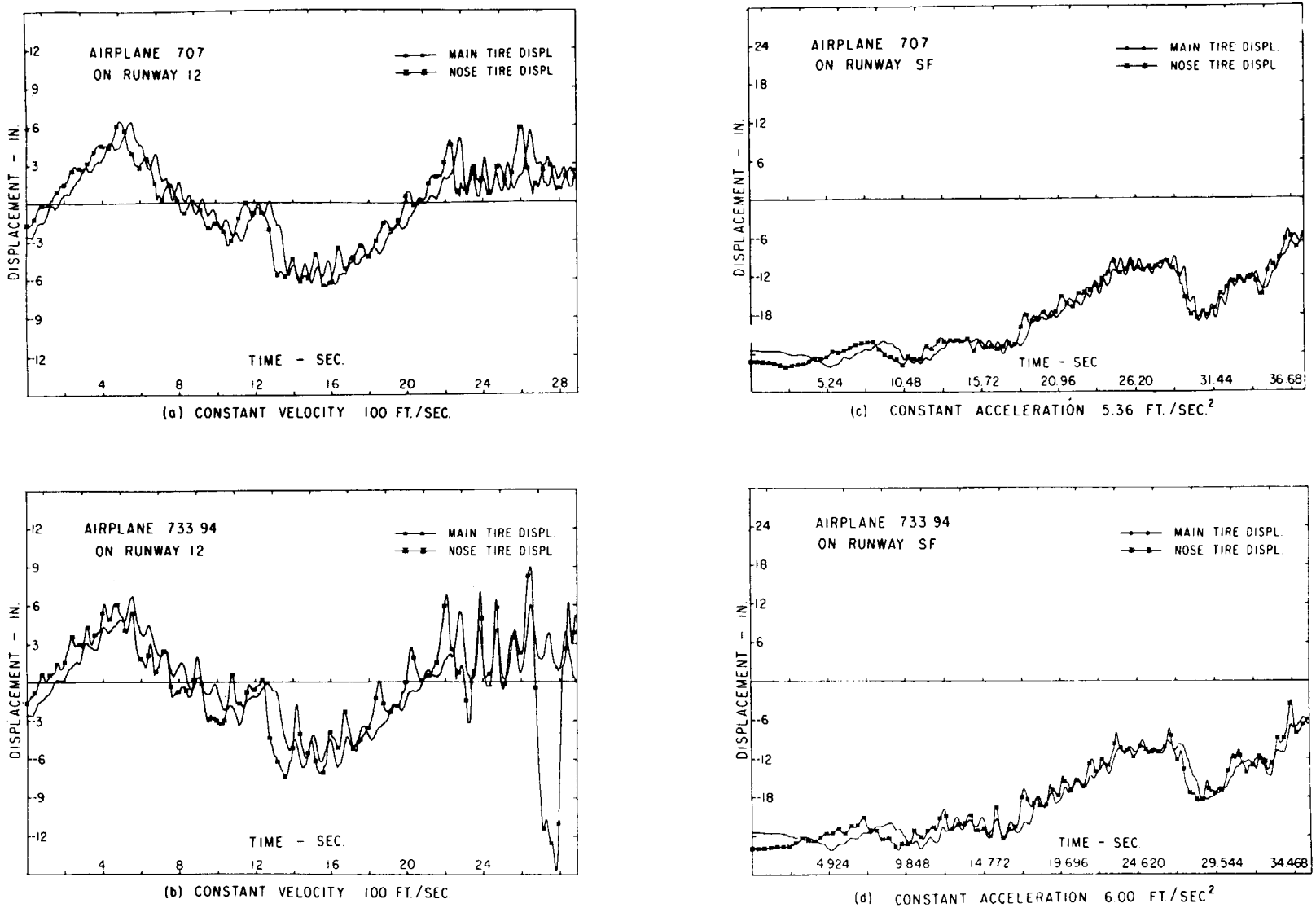


FIG. 9 VERTICAL DISPLACEMENT OF WHEEL MASSES

FLEXURAL MODES INCLUDED

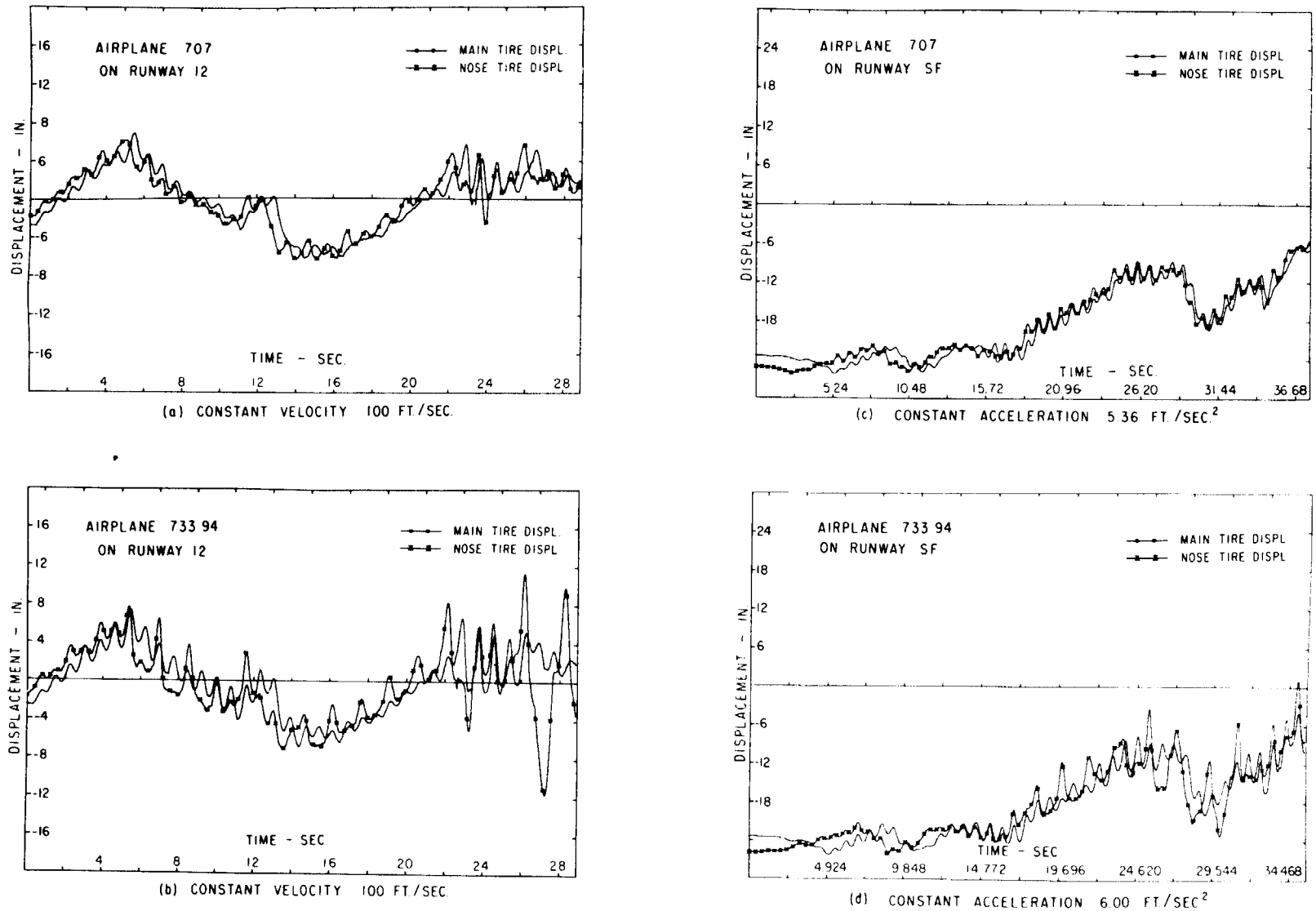
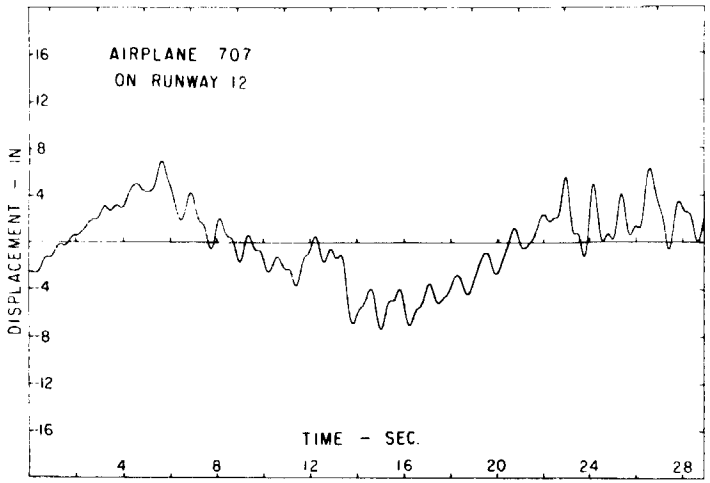
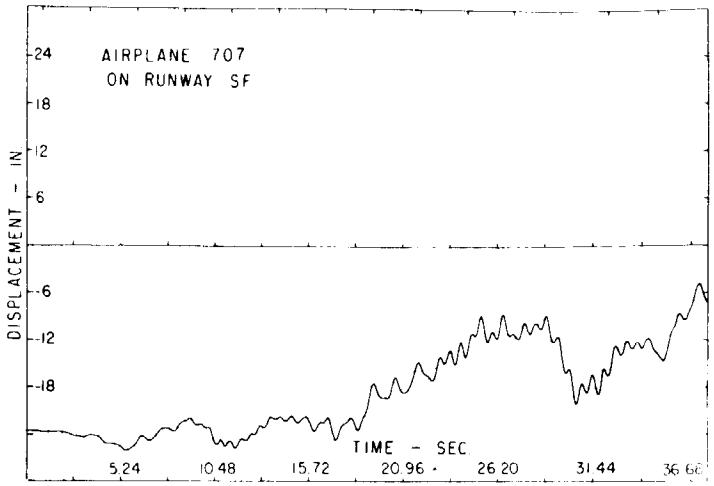


FIG. 10 VERTICAL DISPLACEMENT OF WHEEL MASSES

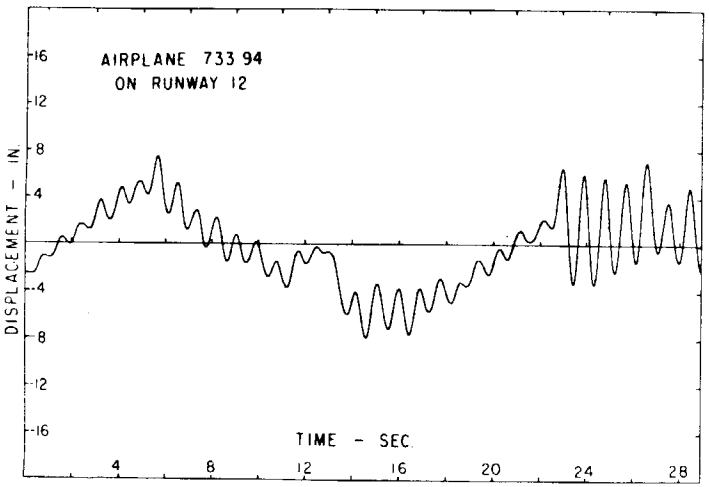
RIGID BODY MODES ONLY



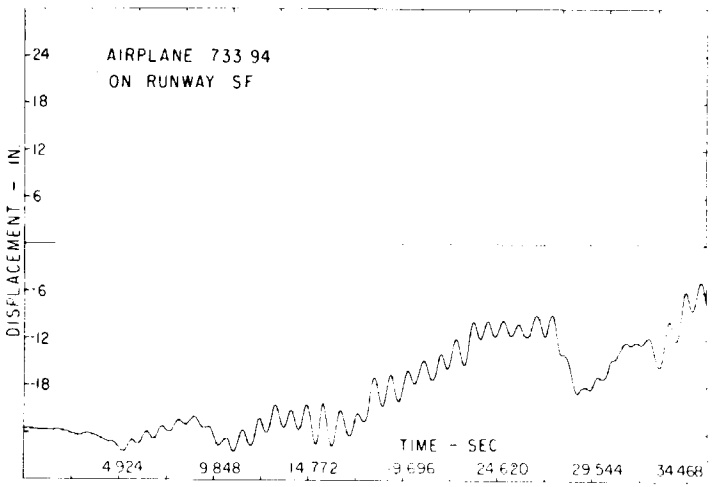
(a) CONSTANT VELOCITY 100 FT./SEC.



(c) CONSTANT ACCELERATION 5.36 FT./SEC.^{2}



(b) CONSTANT VELOCITY 100 FT./SEC.



(d) CONSTANT ACCELERATION 6.00 FT./SEC.^{2}

FIG. 11 RIGID BODY TRANSLATION

FLEXURAL MODES INCLUDED

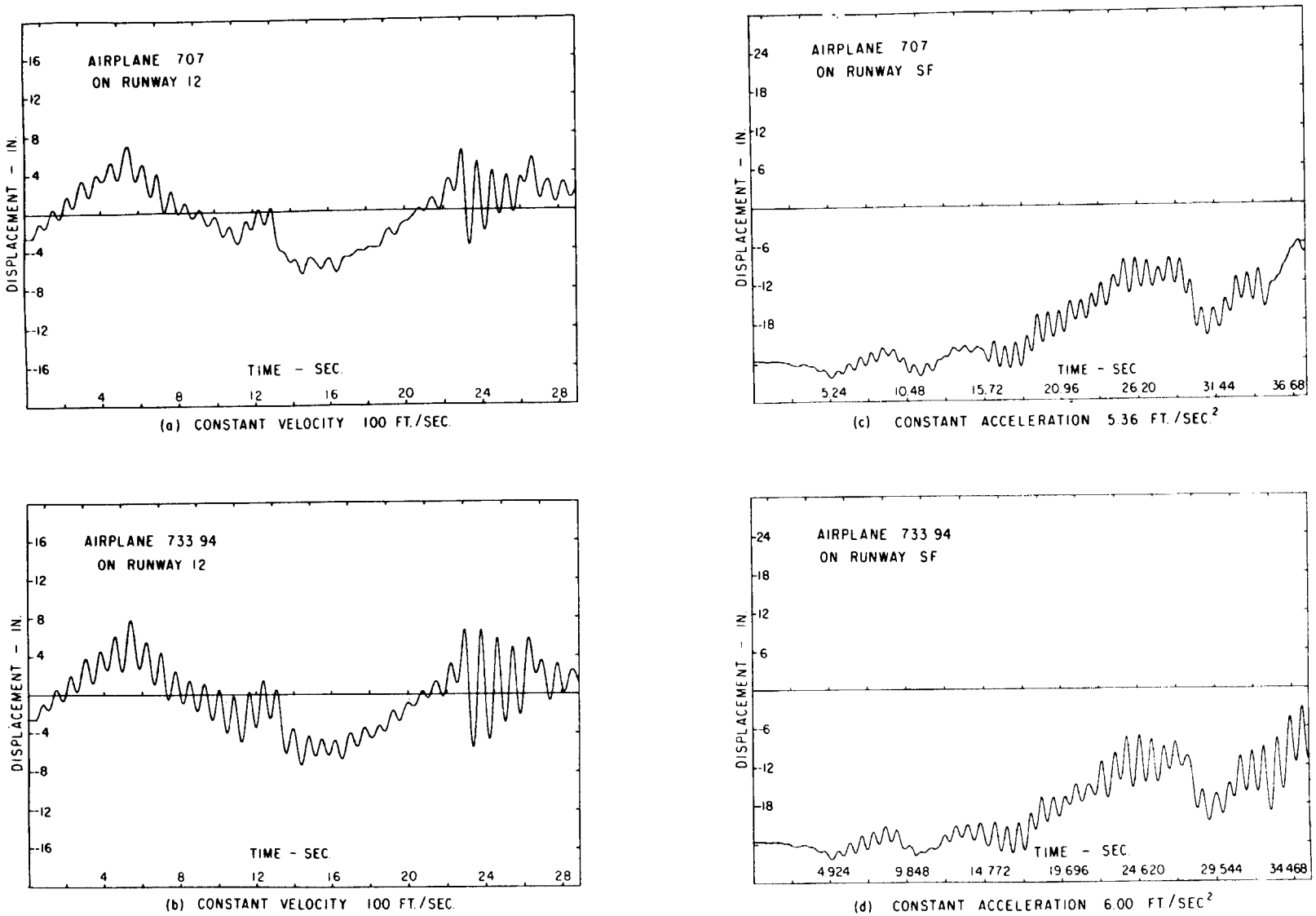


FIG. 12 RIGID BODY TRANSLATION

RIGID BODY MODES ONLY

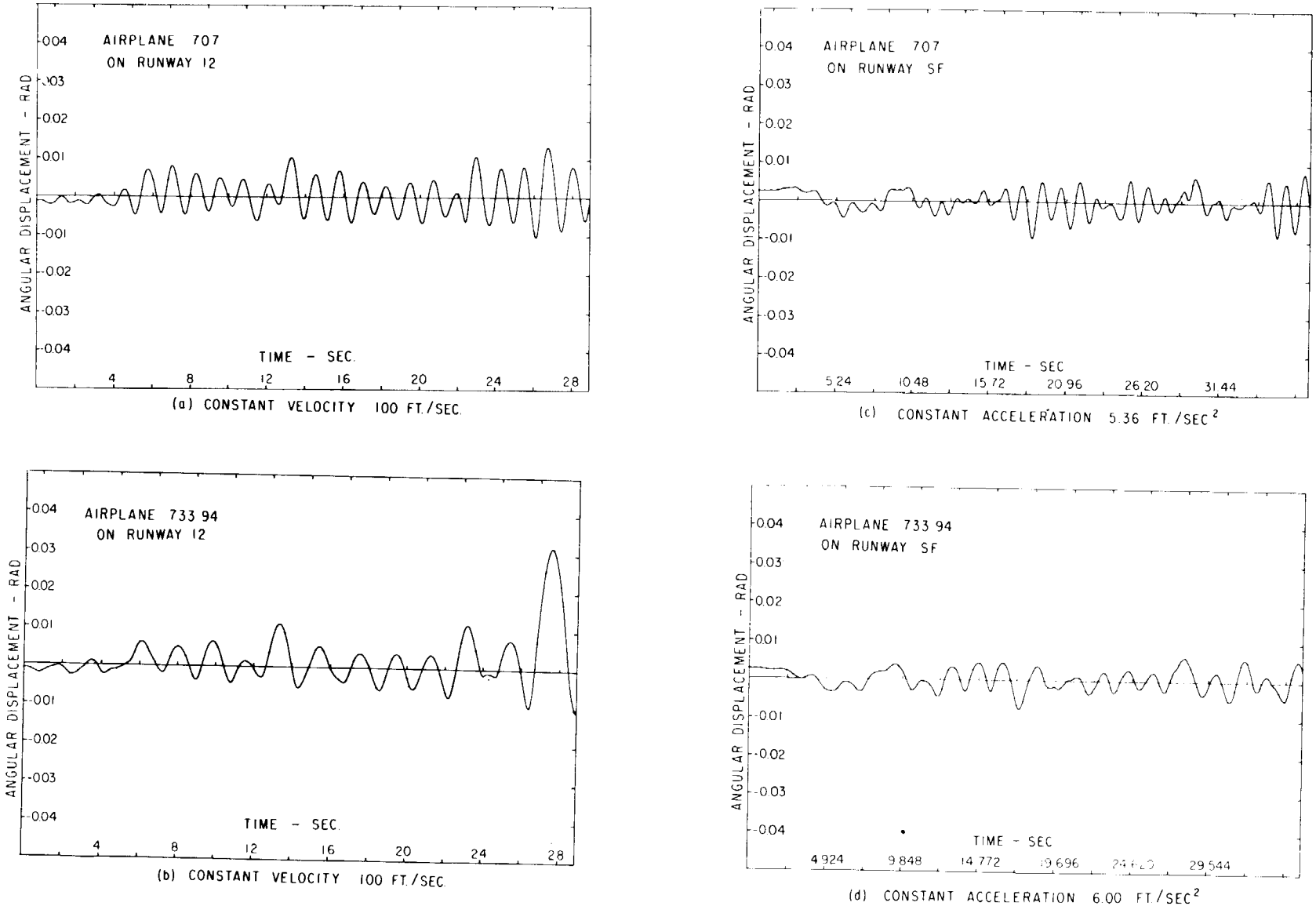
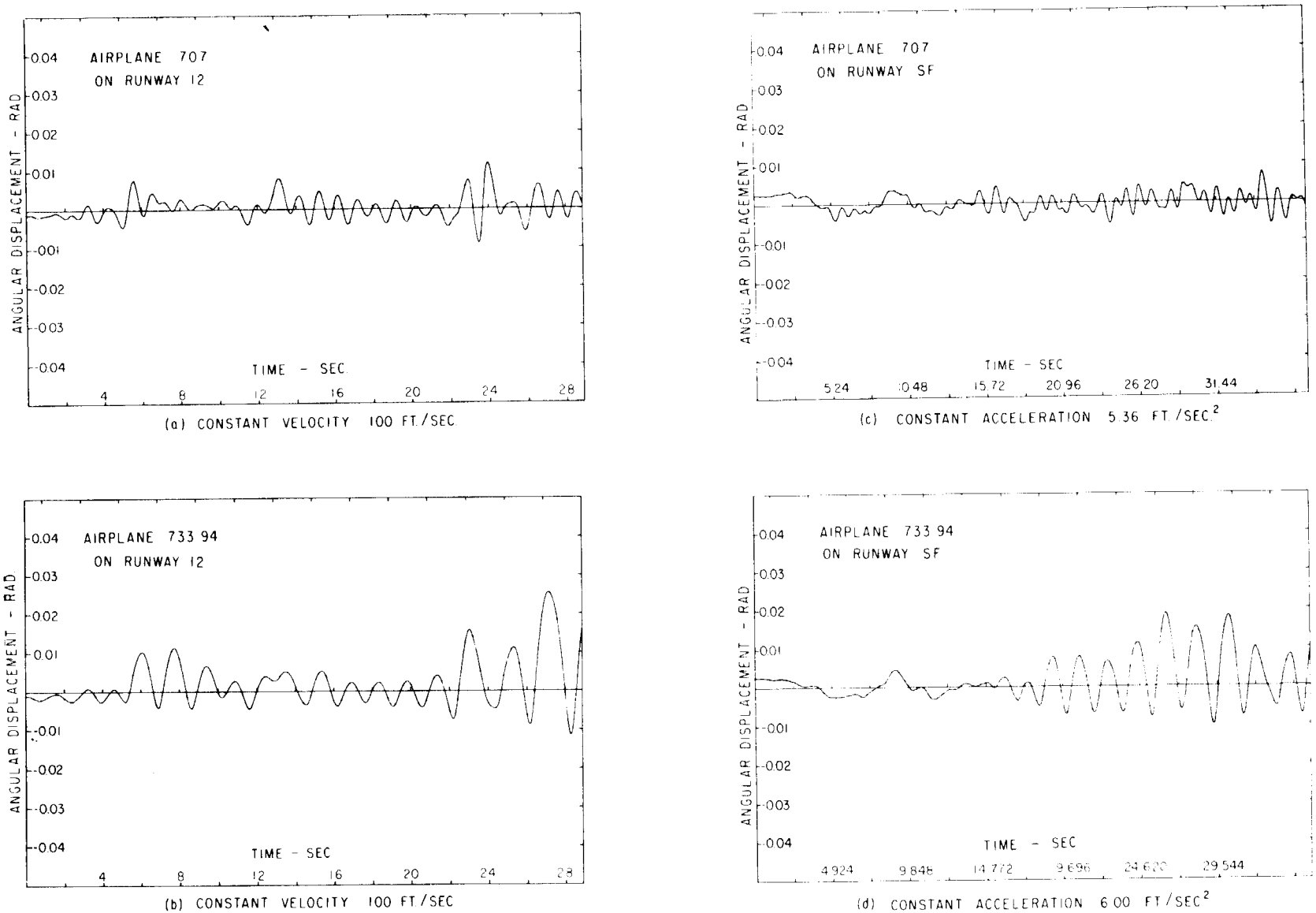


FIG. 13 RIGID BODY ROTATION

FLEXURAL MODES INCLUDED



(a) CONSTANT VELOCITY 100 FT./SEC

(b) CONSTANT VELOCITY 100 FT./SEC

(c) CONSTANT ACCELERATION 5.36 FT./SEC.^{2}

(d) CONSTANT ACCELERATION 6.00 FT./SEC^2

FIG. 14 RIGID BODY ROTATION

RIGID BODY MODES ONLY

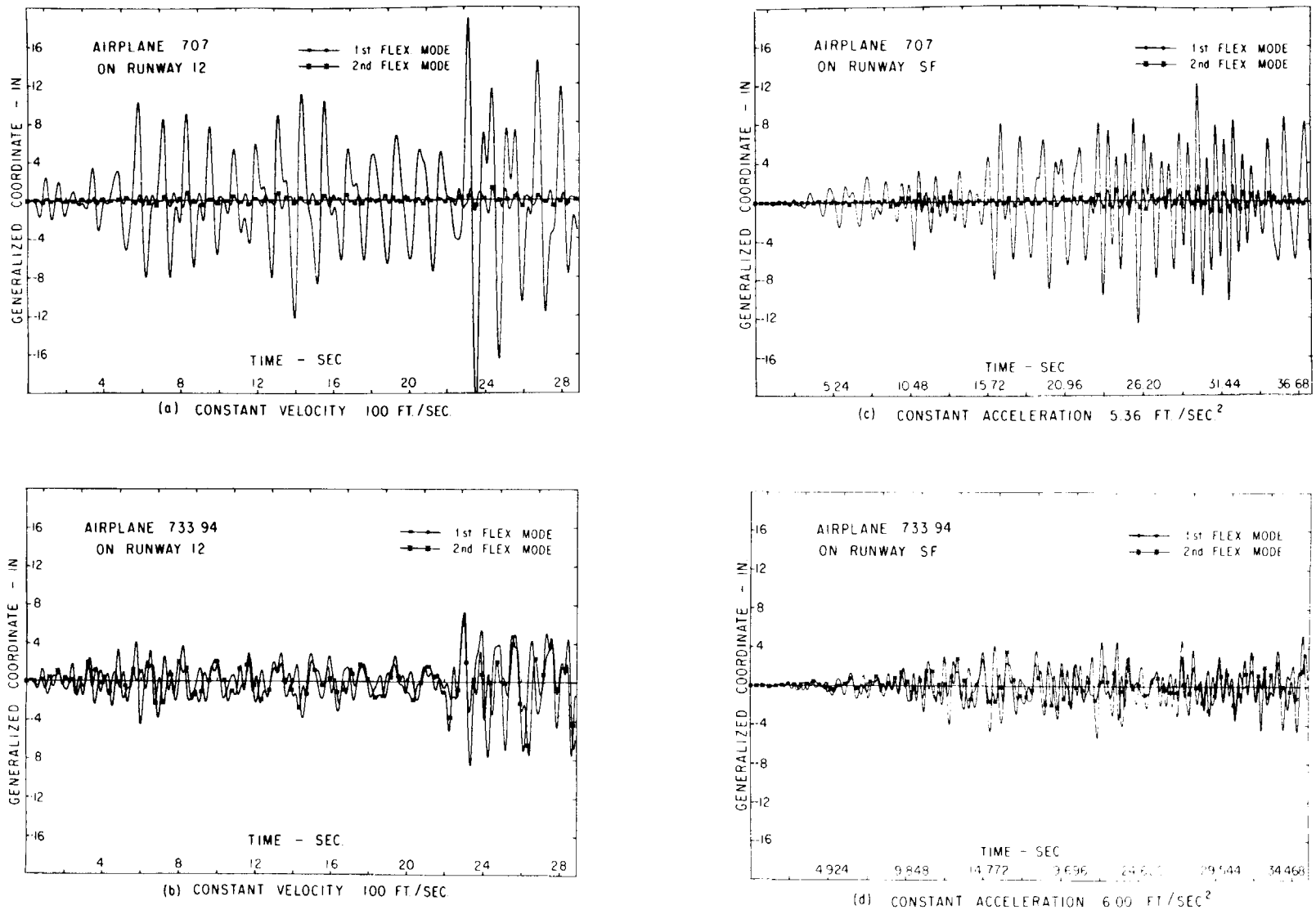


FIG. 15 GENERALIZED COORDINATE OF 1st & 2nd FLEXURAL MODES

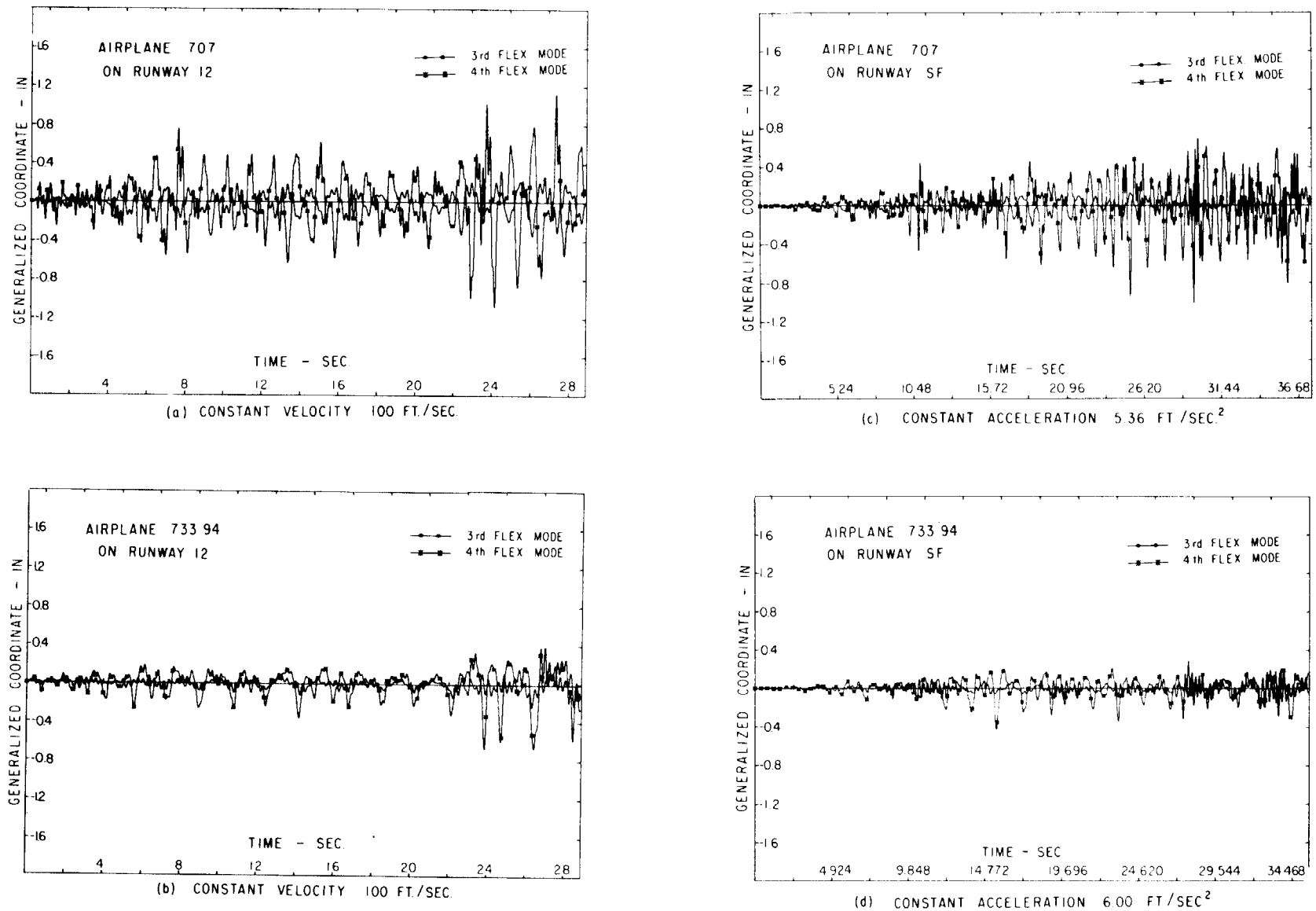


FIG. 16 GENERALIZED COORDINATE OF 3rd & 4th FLEXURAL MODES

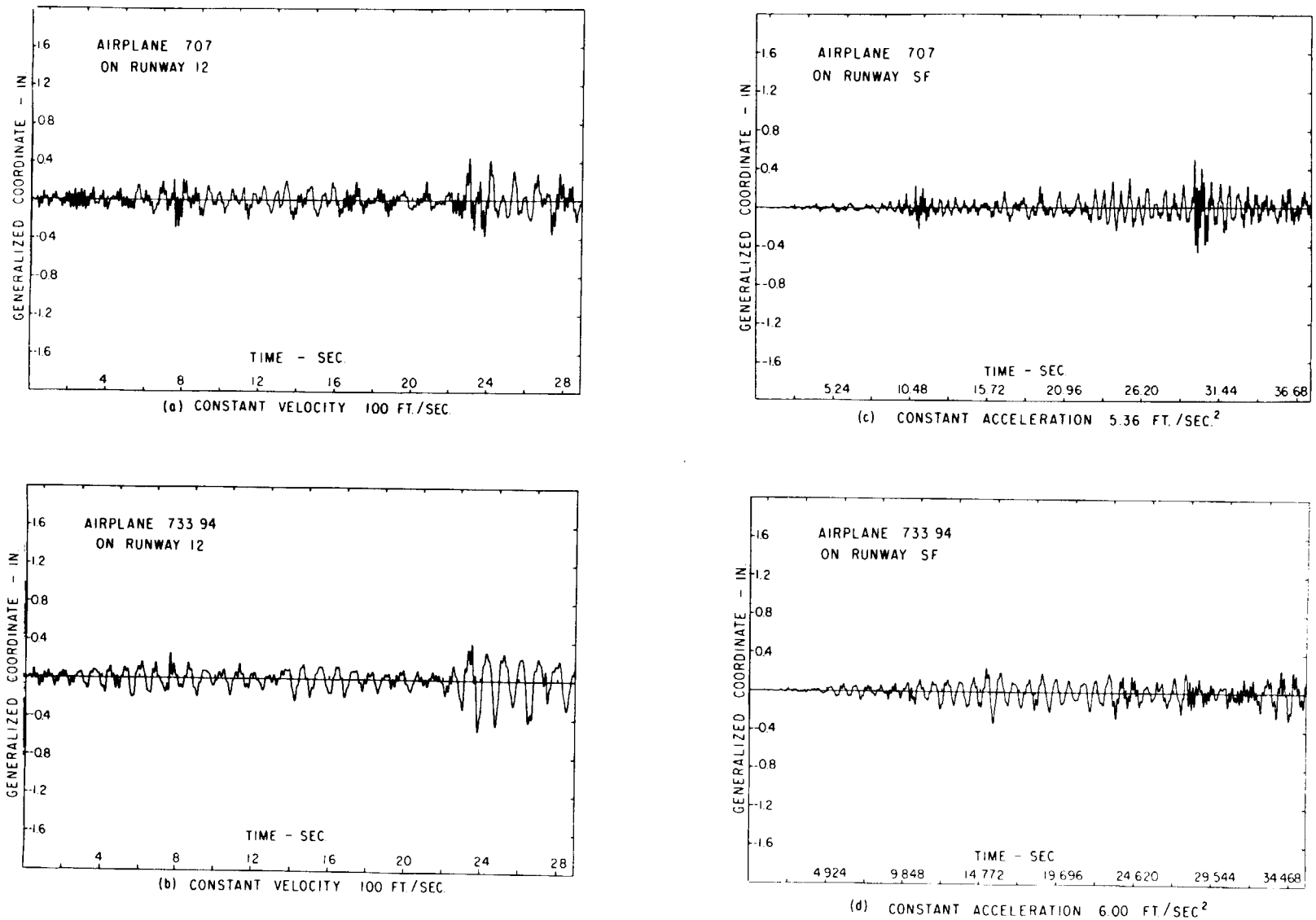


FIG. 17 GENERALIZED COORDINATE OF 5th FLEXURAL MODE

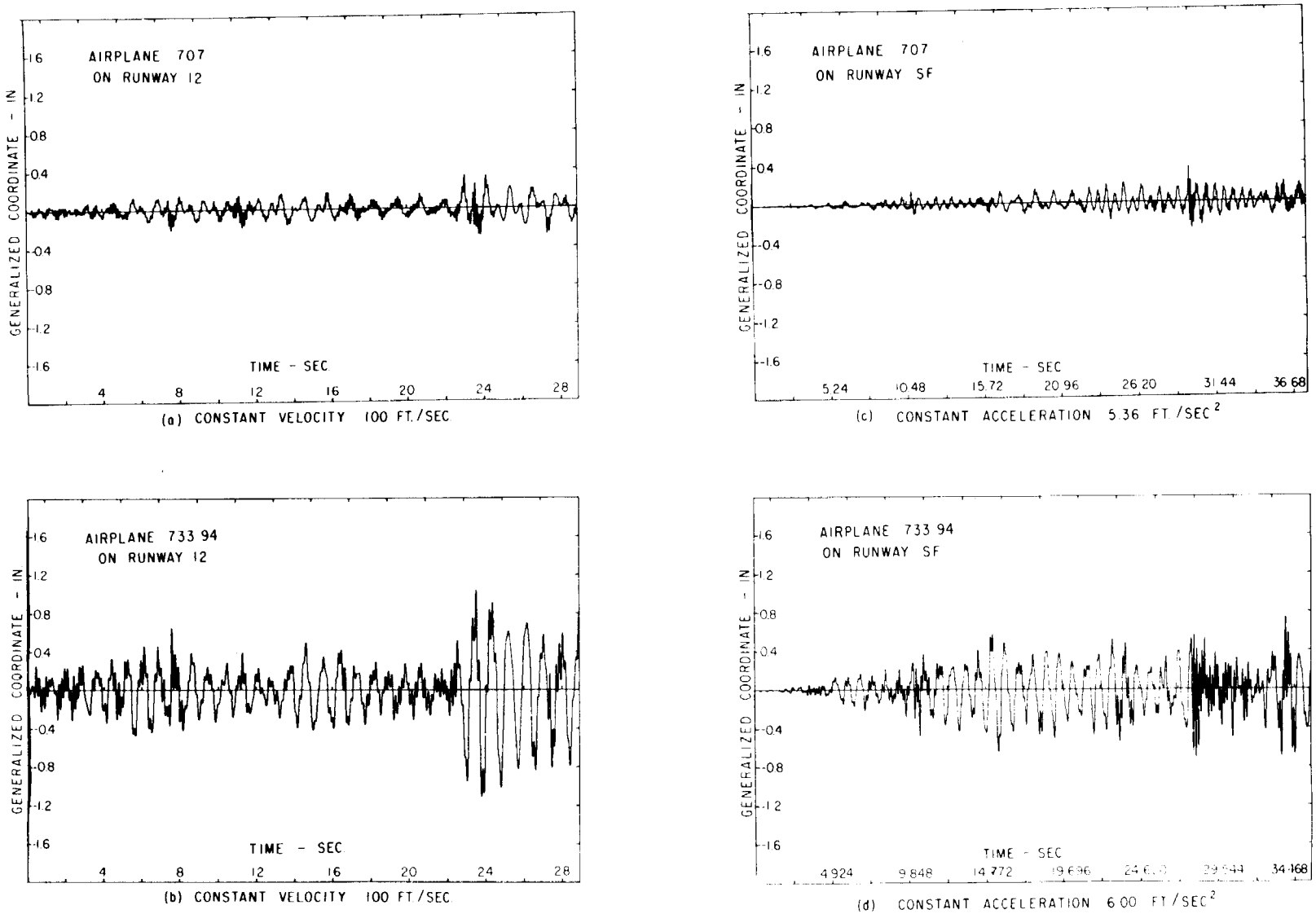


FIG. 18 GENERALIZED COORDINATE OF 6th FLEXURAL MODE

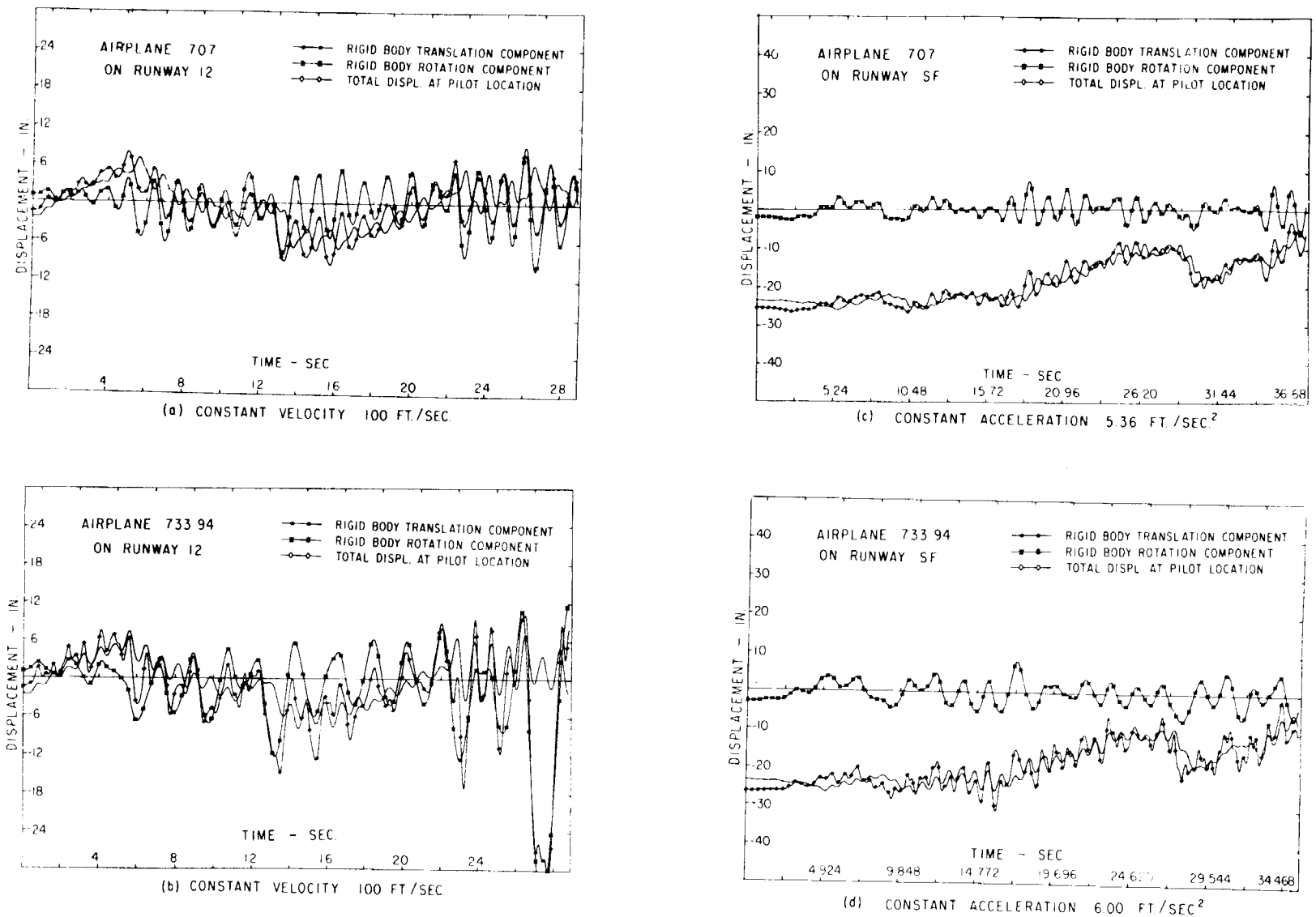


FIG. 19 VERTICAL DISPLACEMENT AT PILOT LOCATION

FLEXURAL MODES INCLUDED

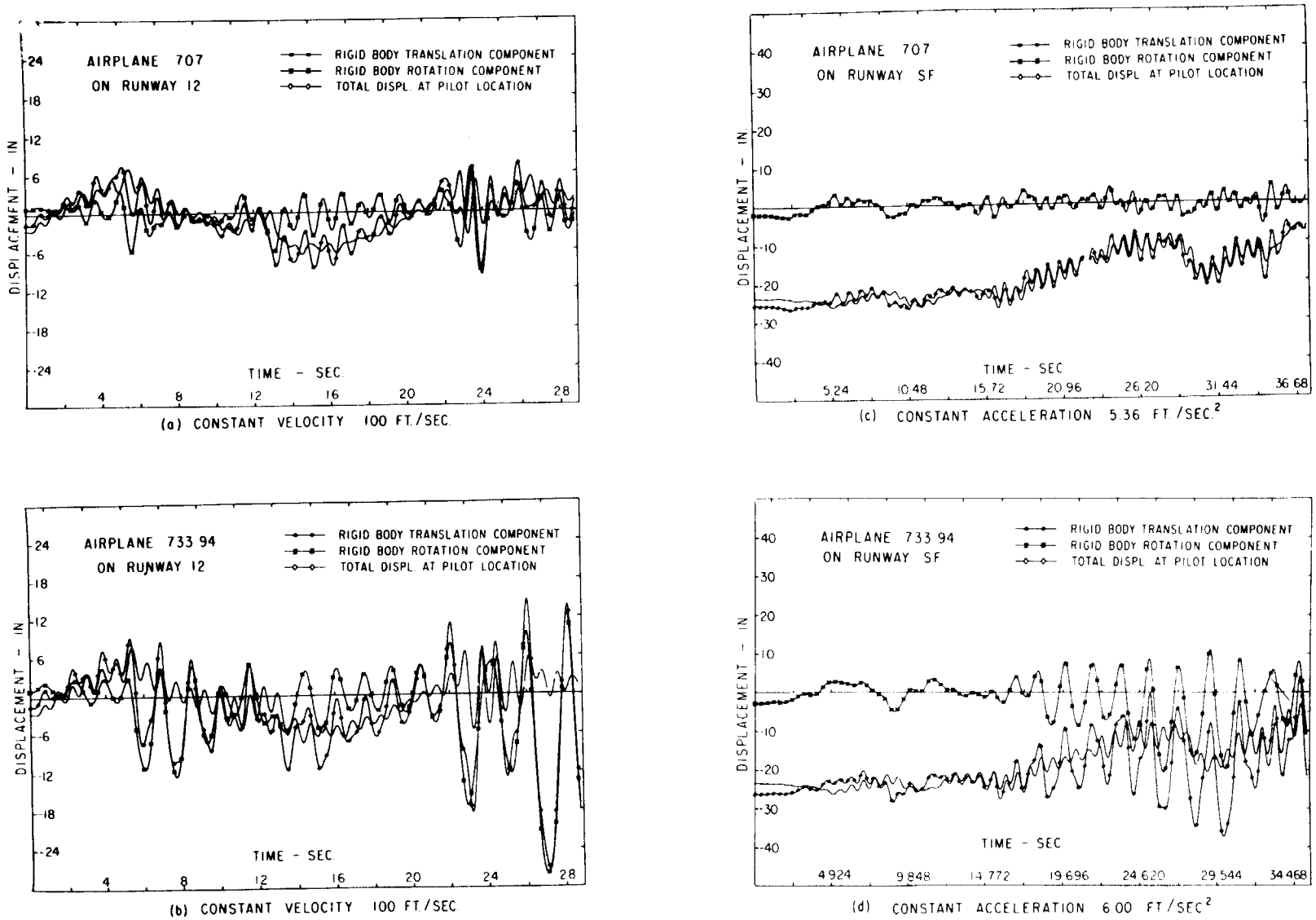
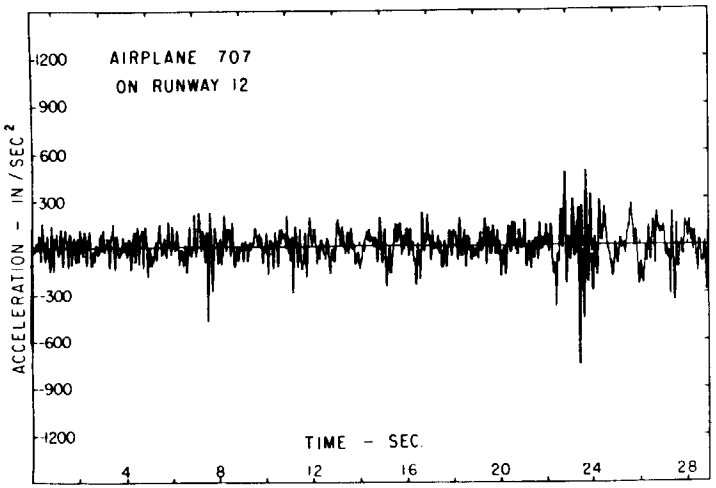
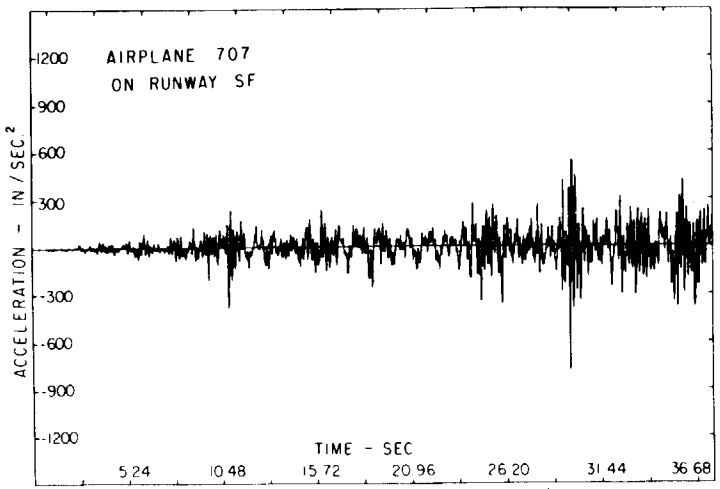


FIG. 20 VERTICAL DISPLACEMENT AT PILOT LOCATION

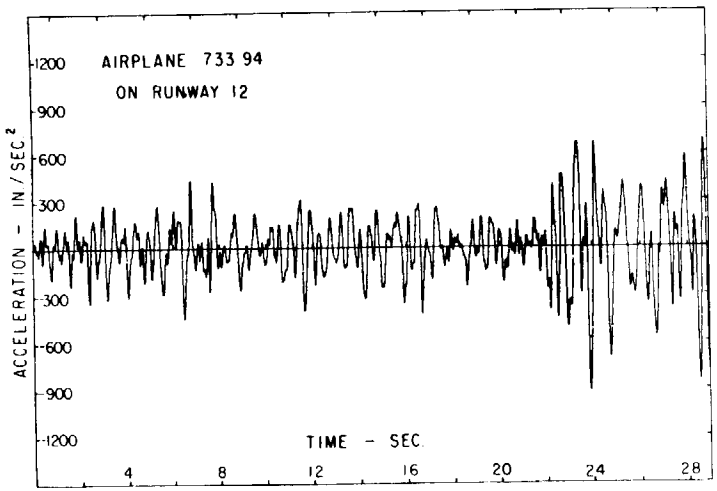
RIGID BODY MODES ONLY



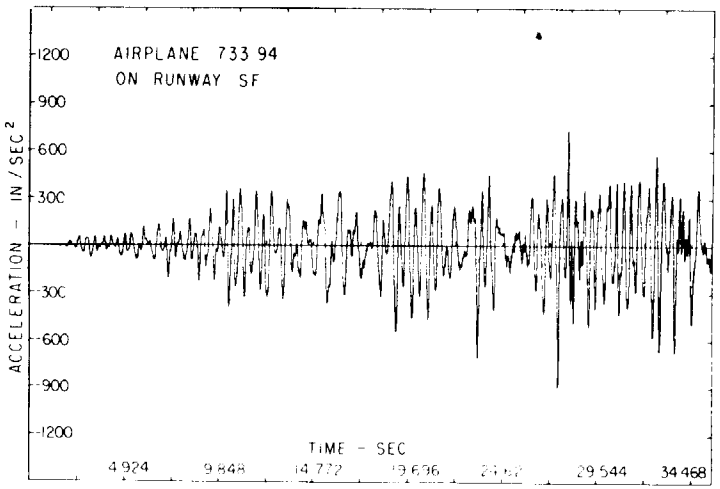
(a) CONSTANT VELOCITY 100 FT./SEC.



(c) CONSTANT ACCELERATION 5.36 FT./SEC.²



(b) CONSTANT VELOCITY 100 FT./SEC.



(d) CONSTANT ACCELERATION 6.00 FT/SEC.²

FIG. 21 VERTICAL ACCELERATION AT PILOT LOCATION

FLEXURAL MODES INCLUDED

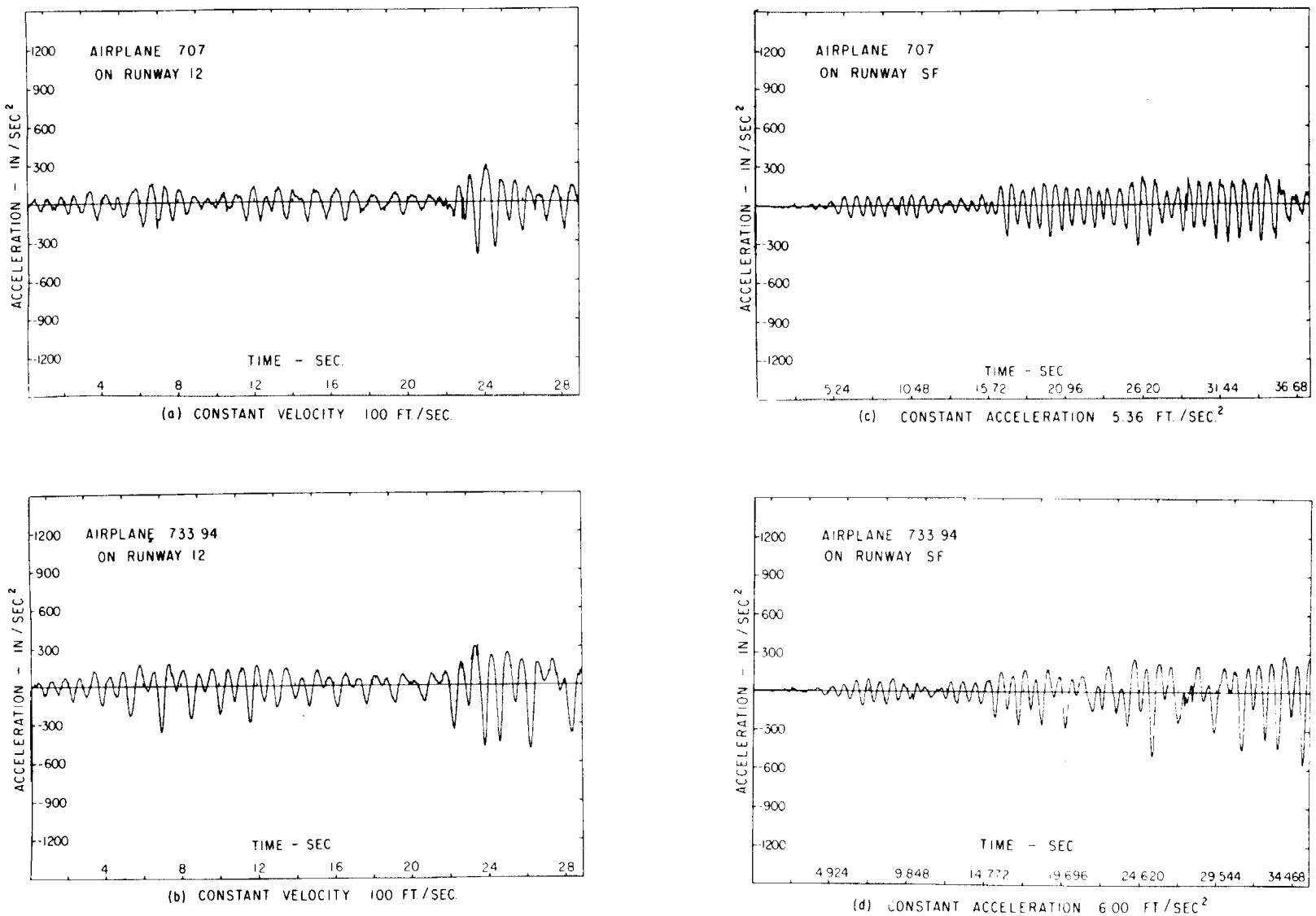
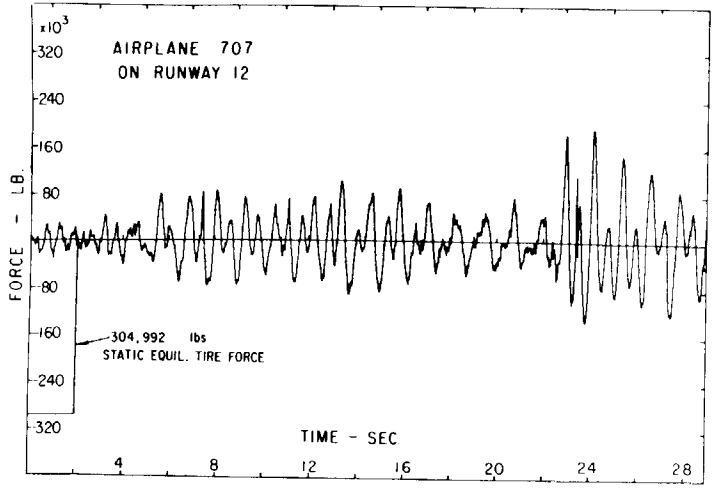
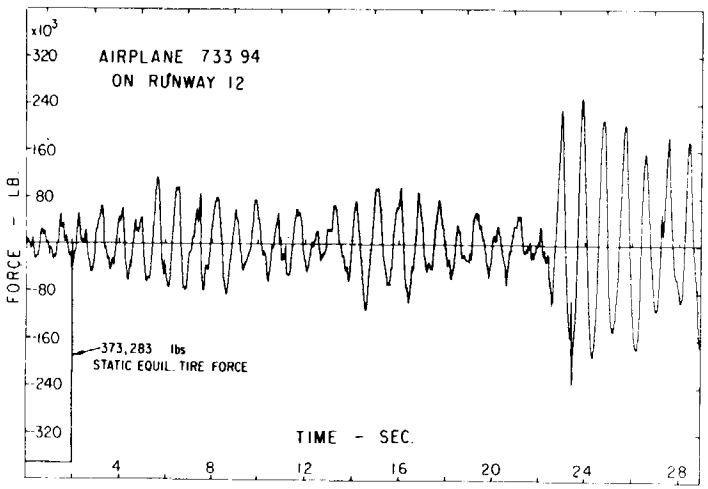


FIG. 22 VERTICAL ACCELERATION AT PILOT LOCATION

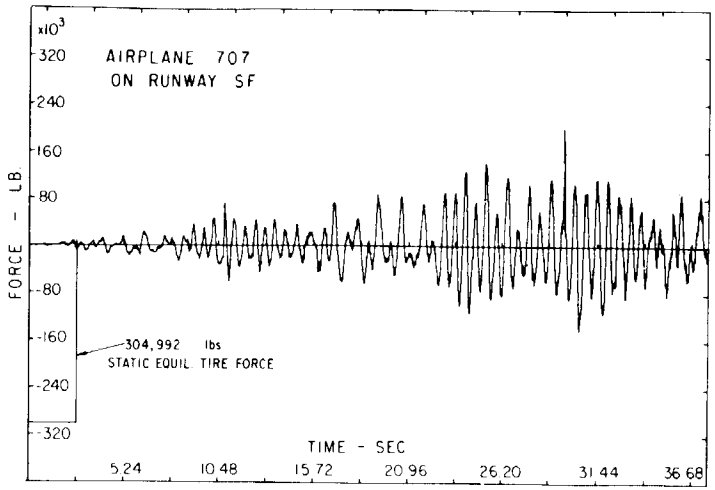
RIGID BODY MODES ONLY



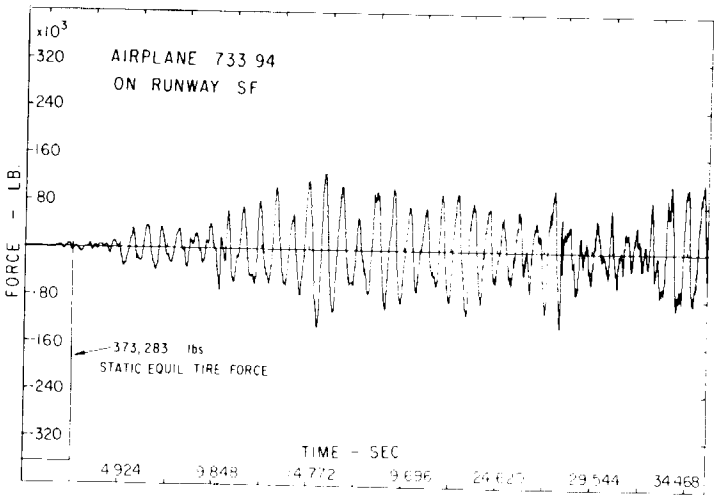
(a) CONSTANT VELOCITY 100 FT./SEC.



(b) CONSTANT VELOCITY 100 FT./SEC.



(c) CONSTANT ACCELERATION 5.36 FT./SEC.^{2}



(d) CONSTANT ACCELERATION 6.00 FT./SEC.^{2}

FIG. 23 MAIN TIRE FORCE

FLEXURAL MODES INCLUDED

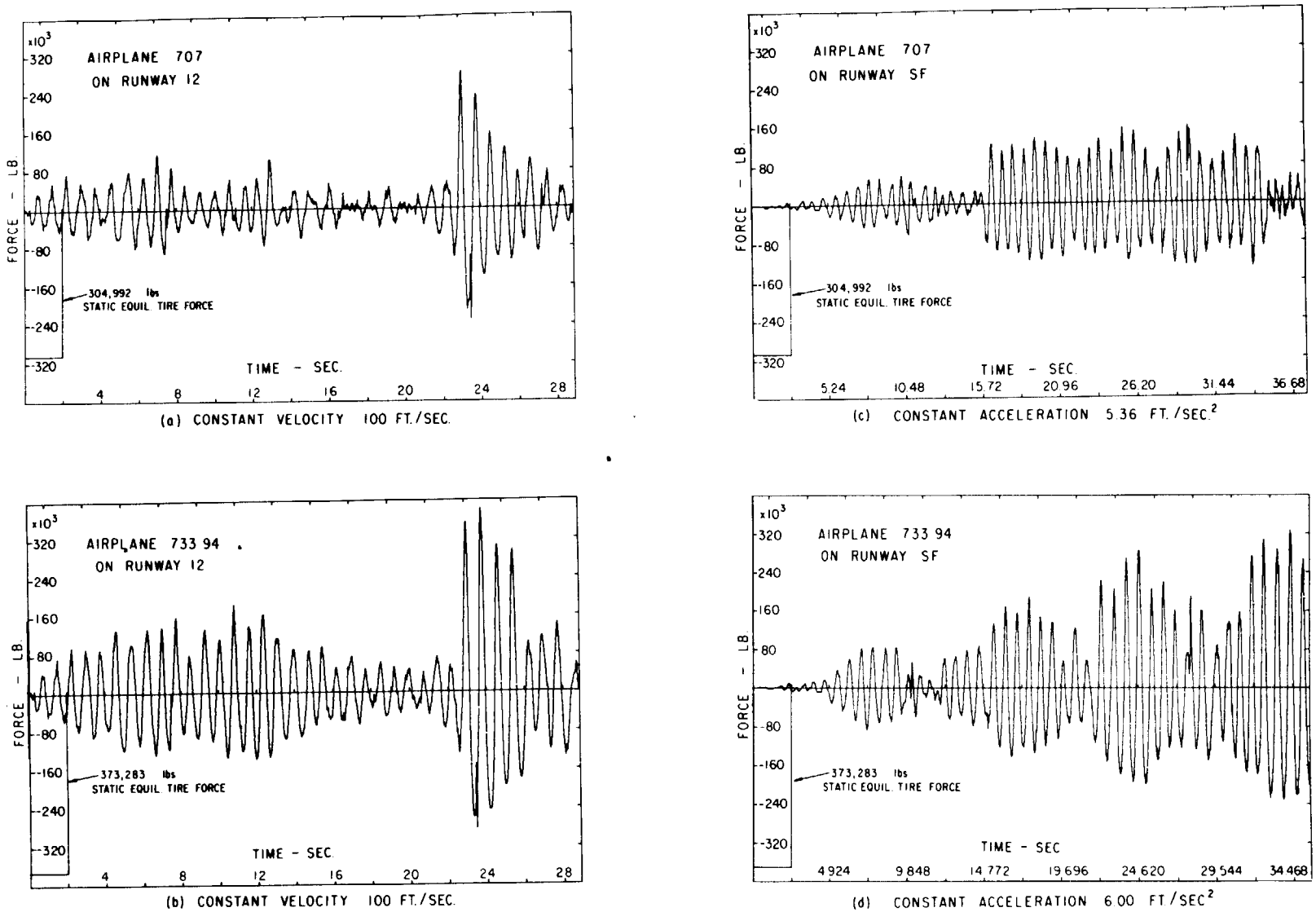


FIG. 24 MAIN TIRE FORCE

RIGID BODY MODES ONLY

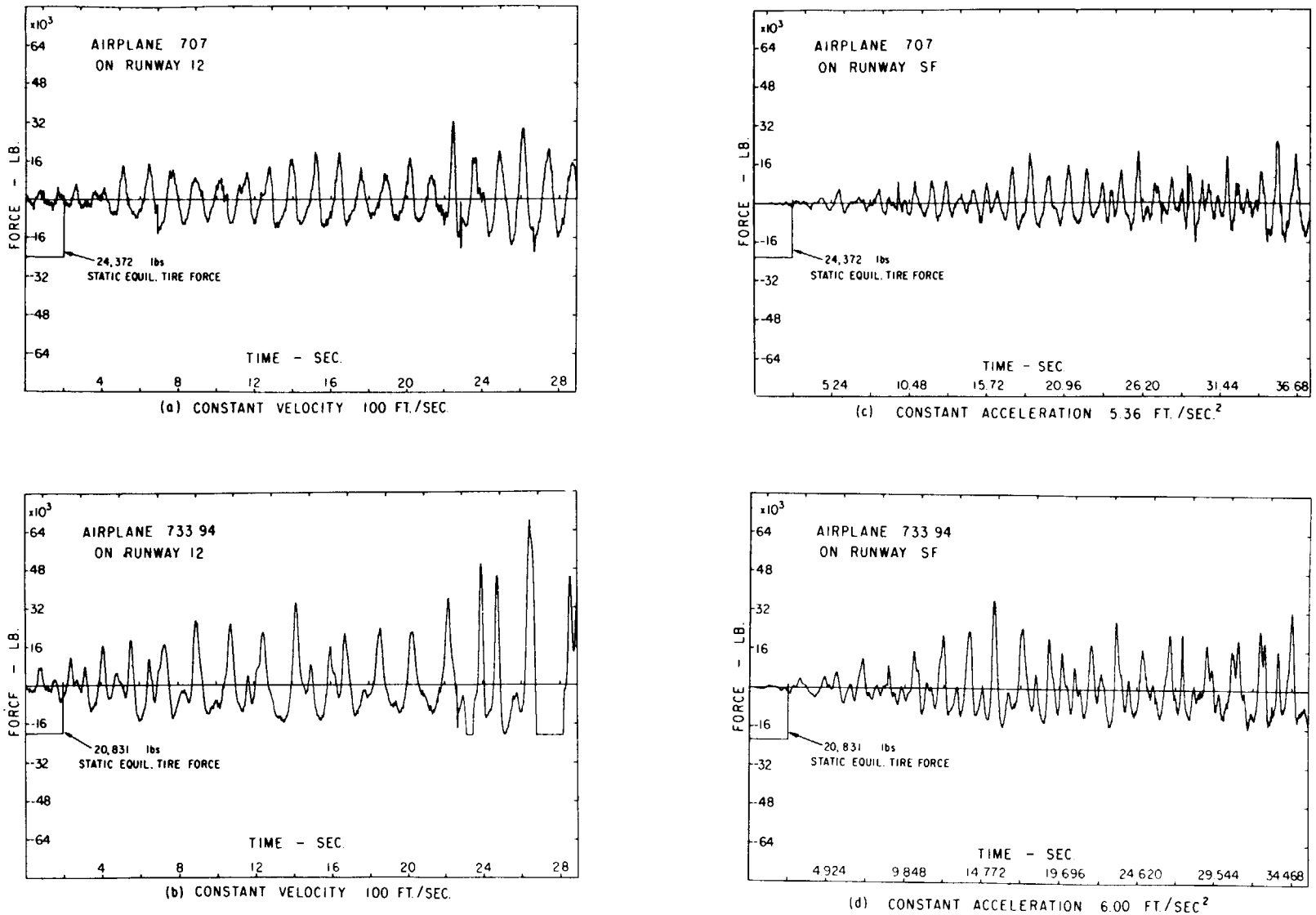
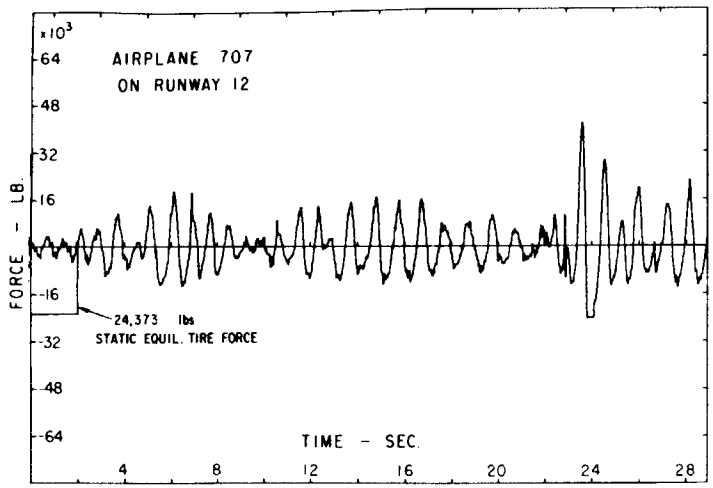
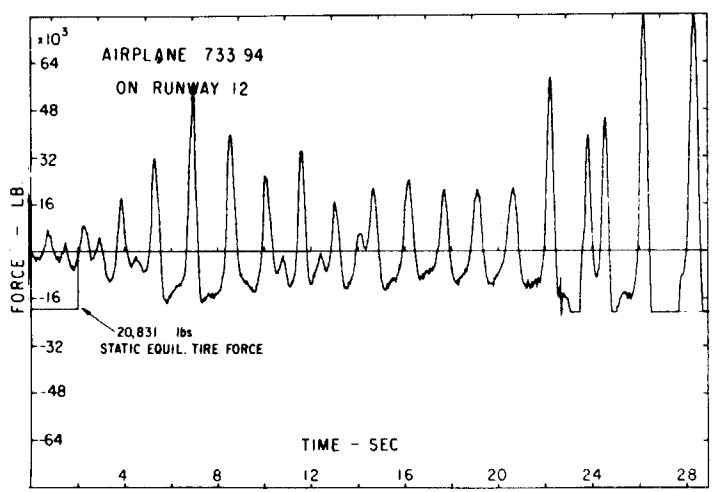


FIG. 25 NOSE TIRE FORCE

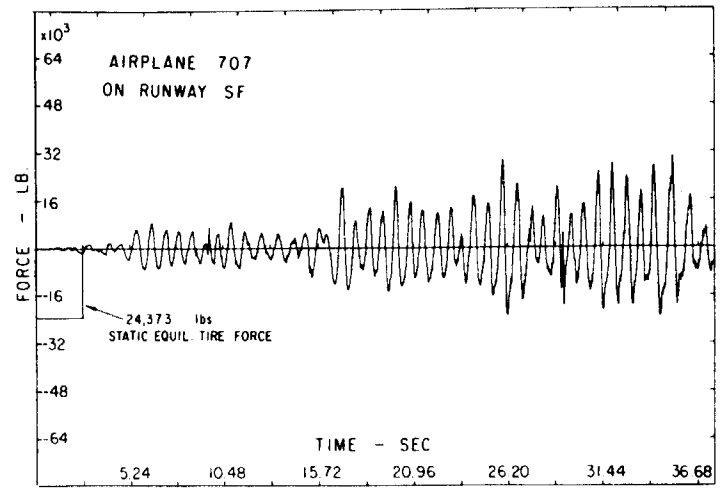
FLEXURAL MODES INCLUDED



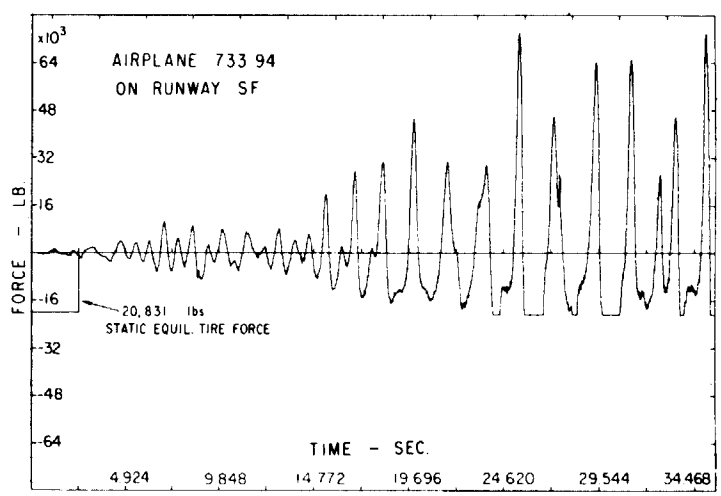
(a) CONSTANT VELOCITY 100 FT./SEC.



(b) CONSTANT VELOCITY 100 FT./SEC.



(c) CONSTANT ACCELERATION 5.36 FT./SEC.^{2}



(d) CONSTANT ACCELERATION 6.00 FT./SEC.^{2}

FIG. 26 NOSE TIRE FORCE

RIGID BODY MODES ONLY

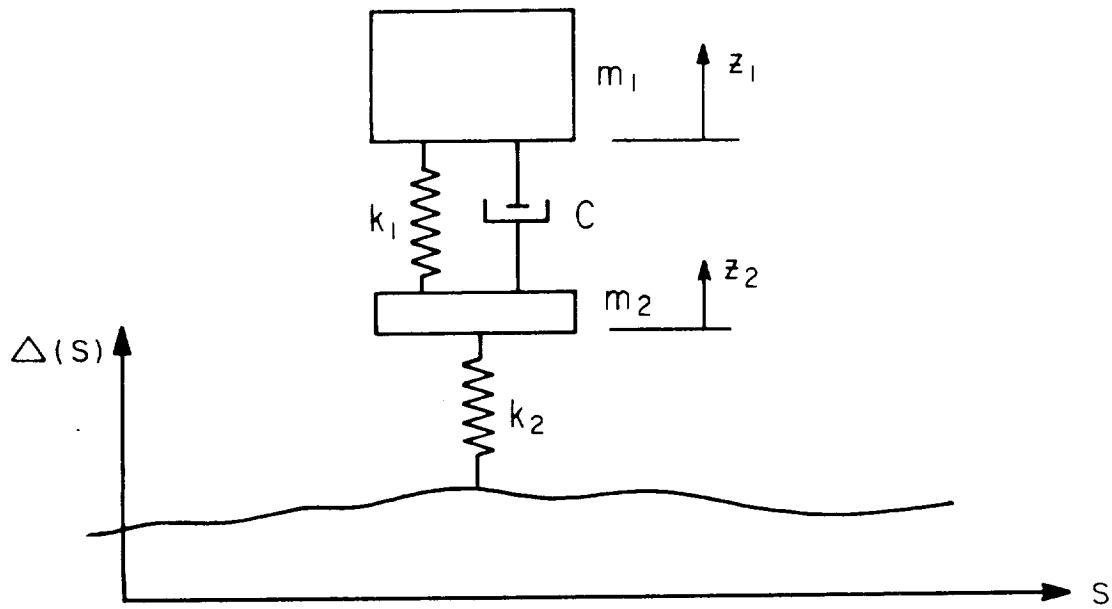


FIG. 27 TWO DEGREE OF FREEDOM SYSTEM USED IN STATISTICAL ANALYSIS

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
0	0.214										
2	.224	112	0.071	222	-0.058	332	-0.210	442	-0.381	552	-0.487
4	.220	114	.062	224	-.047	334	-.220	444	-.377	554	-.480
6	.223	116	.053	226	-.041	336	-.238	446	-.369	556	-.480
8	.222	118	.050	228	-.057	338	-.241	448	-.365	558	-.475
10	.225	120	.052	230	-.068	340	-.231	450	-.364	560	-.465
12	.220	122	.048	232	-.069	342	-.226	452	-.385	562	-.450
14	.220	124	.050	234	-.077	344	-.228	454	-.388	564	-.439
16	.221	126	.041	236	-.097	346	-.231	456	-.371	566	-.431
18	.212	128	.034	238	-.098	348	-.238	458	-.362	568	-.428
20	.212	130	.031	240	-.105	350	-.244	460	-.359	570	-.422
22	.212	132	.036	242	-.108	352	-.235	462	-.358	572	-.432
24	.213	134	.039	244	-.105	354	-.232	464	-.344	574	-.427
26	.226	136	.034	246	-.115	356	-.235	466	-.338	576	-.428
28	.230	138	.023	248	-.118	358	-.240	468	-.328	578	-.420
30	.232	140	.015	250	-.124	360	-.247	470	-.332	580	-.416
32	.214	142	.012	252	-.118	362	-.251	472	-.356	582	-.410
34	.201	144	.014	254	-.110	364	-.251	474	-.360	584	-.424
36	.185	146	.025	256	-.110	366	-.245	476	-.360	586	-.423
38	.174	148	.038	258	-.121	368	-.241	478	-.364	588	-.410
40	.174	150	.042	260	-.135	370	-.240	480	-.367	590	-.407
42	.171	152	.022	262	-.140	372	-.238	482	-.377	592	-.408
44	.168	154	.011	264	-.145	374	-.242	484	-.372	594	-.408
46	.162	156	.009	266	-.146	376	-.254	486	-.374	596	-.371
48	.156	158	.009	268	-.150	378	-.276	488	-.368	598	-.368
50	.151	160	.011	270	-.148	380	-.274	490	-.372	600	-.364
52	.152	162	.019	272	-.148	382	-.272	492	-.374	602	-.368
54	.144	164	.014	274	-.148	384	-.279	494	-.372	604	-.366
56	.143	166	.000	276	-.161	386	-.285	496	-.370	606	-.368
58	.141	168	-.010	278	-.166	388	-.292	498	-.379	608	-.368
60	.140	170	-.008	280	-.172	390	-.290	500	-.390	610	-.365
62	.150	172	-.007	282	-.178	392	-.295	502	-.397	612	-.370
64	.144	174	-.002	284	-.180	394	-.295	504	-.405	614	-.364
66	.152	176	.004	286	-.197	396	-.292	506	-.415	616	-.368
68	.153	178	-.006	288	-.205	398	-.299	508	-.427	618	-.365
70	.148	180	-.007	290	-.206	400	-.316	510	-.429	620	-.360
72	.145	182	-.018	292	-.218	402	-.323	512	-.430	622	-.356
74	.135	184	-.020	294	-.223	404	-.327	514	-.441	624	-.344
76	.130	186	-.030	296	-.226	406	-.325	516	-.446	626	-.328
78	.132	188	-.028	298	-.206	408	-.316	518	-.455	628	-.326
80	.138	190	-.030	300	-.204	410	-.310	520	-.460	630	-.317
82	.135	192	-.026	302	-.217	412	-.301	522	-.462	632	-.308
84	.131	194	-.025	304	-.226	414	-.308	524	-.462	634	-.300
86	.120	196	-.038	306	-.221	416	-.315	526	-.469	636	-.299
88	.110	198	-.058	308	-.220	418	-.319	528	-.481	638	-.298
90	.106	200	-.068	310	-.221	420	-.324	530	-.494	640	-.294
92	.104	202	-.058	312	-.221	422	-.324	532	-.509	642	-.288
94	.104	204	-.060	314	-.218	424	-.335	534	-.521	644	-.288
96	.095	206	-.069	316	-.209	426	-.344	536	-.527	646	-.295
98	.085	208	-.068	318	-.209	428	-.358	538	-.528	648	-.286
100	.069	210	-.061	320	-.196	430	-.359	540	-.528	650	-.285
102	.083	212	-.066	322	-.188	432	-.355	542	-.528	652	-.274
104	.084	214	-.073	324	-.189	434	-.365	544	-.525	654	-.264
106	.081	216	-.081	326	-.191	436	-.374	546	-.521	656	-.251
108	.078	218	-.075	328	-.201	438	-.383	548	-.508	658	-.255
110	.075	220	-.064	330	-.197	440	-.386	550	-.500	660	-.262

TABLE 1. RUNWAY ELEVATION DATA - RUNWAY 12

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
662	-0.275	772	-0.090	882	0.004	992	0.080	1,102	0.198	1,212	0.061
664	-.282	774	-.078	884	.002	994	.074	1,104	.206	1,214	.055
666	-.288	776	-.070	886	.006	996	.075	1,106	.219	1,216	.062
668	-.284	778	-.078	888	.008	998	.076	1,108	.216	1,218	.072
670	-.278	780	-.085	890	.009	1,000	.074	1,110	.222	1,220	.071
672	-.269	782	-.096	892	.002	1,002	.082	1,112	.234	1,222	.064
674	-.269	784	-.104	894	.003	1,004	.093	1,114	.257	1,224	.072
676	-.282	786	-.109	896	.003	1,006	.095	1,116	.281	1,226	.075
678	-.278	788	-.111	898	.012	1,008	.102	1,118	.254	1,228	.076
680	-.281	790	-.107	900	.020	1,010	.104	1,120	.241	1,230	.062
682	-.278	792	-.100	902	.015	1,012	.099	1,122	.233	1,232	.057
684	-.266	794	-.100	904	.009	1,014	.101	1,124	.231	1,234	.051
686	-.264	796	-.088	906	.002	1,016	.104	1,126	.226	1,236	.050
688	-.261	798	-.082	908	.005	1,018	.113	1,128	.223	1,238	.049
690	-.254	800	-.077	910	.006	1,020	.111	1,130	.218	1,240	.051
692	-.246	802	-.074	912	.016	1,022	.110	1,132	.208	1,242	.047
694	-.245	804	-.078	914	.018	1,024	.121	1,134	.198	1,244	.043
696	-.230	806	-.069	916	.015	1,026	.141	1,136	.192	1,246	.051
698	-.218	808	-.068	918	.016	1,028	.141	1,138	.188	1,248	.052
700	-.205	810	-.074	920	.023	1,030	.150	1,140	.186	1,250	.048
702	-.188	812	-.065	922	.026	1,032	.156	1,142	.186	1,252	.047
704	-.182	814	-.066	924	.030	1,034	.158	1,144	.179	1,254	.041
706	-.182	816	-.068	926	.030	1,036	.152	1,146	.170	1,256	.029
708	-.182	818	-.056	928	.034	1,038	.143	1,148	.172	1,258	.010
710	-.187	820	-.060	930	.040	1,040	.136	1,150	.170	1,260	.006
712	-.187	822	-.049	932	.028	1,042	.132	1,152	.173	1,262	.000
714	-.189	824	-.045	934	.034	1,044	.126	1,154	.172	1,264	-.009
716	-.183	826	-.047	936	.030	1,046	.121	1,156	.168	1,266	-.022
718	-.175	828	-.040	938	.035	1,048	.132	1,158	.166	1,268	-.010
720	-.180	830	-.048	940	.034	1,050	.138	1,160	.172	1,270	-.011
722	-.186	832	-.046	942	.042	1,052	.137	1,162	.166	1,272	-.009
724	-.181	834	-.038	944	.046	1,054	.145	1,164	.155	1,274	-.004
726	-.175	836	-.034	946	.054	1,056	.154	1,166	.153	1,276	.008
728	-.164	838	-.036	948	.051	1,058	.166	1,168	.160	1,278	.006
730	-.160	840	-.031	950	.055	1,060	.172	1,170	.159	1,280	.010
732	-.158	842	-.022	952	.055	1,062	.156	1,172	.158	1,282	.016
734	-.150	844	-.015	954	.059	1,064	.154	1,174	.154	1,284	.023
736	-.159	846	-.009	956	.059	1,066	.150	1,176	.145	1,286	.026
738	-.160	848	-.018	958	.064	1,068	.156	1,178	.141	1,288	.035
740	-.164	850	-.027	960	.061	1,070	.170	1,180	.136	1,290	.044
742	-.148	852	-.028	962	.063	1,072	.169	1,182	.128	1,292	.076
744	-.128	854	-.031	964	.060	1,074	.179	1,184	.122	1,294	.080
746	-.093	856	-.024	966	.059	1,076	.181	1,186	.105	1,296	.076
748	-.060	858	-.020	968	.055	1,078	.190	1,188	.096	1,298	.080
750	-.053	860	-.026	970	.053	1,080	.196	1,190	.090	1,300	.084
752	-.105	862	-.023	972	.059	1,082	.203	1,192	.078	1,302	.080
754	-.120	864	-.028	974	.068	1,084	.216	1,194	.072	1,304	.082
756	-.123	866	-.030	976	.062	1,086	.201	1,196	.073	1,306	.077
758	-.127	868	-.022	978	.054	1,088	.185	1,198	.070	1,308	.080
760	-.125	870	-.014	980	.058	1,090	.176	1,200	.072	1,310	.078
762	-.125	872	-.012	982	.080	1,092	.190	1,202	.072	1,312	.075
764	-.120	874	-.008	984	.084	1,094	.205	1,204	.062	1,314	.087
766	-.121	876	.000	986	.080	1,096	.204	1,206	.059	1,316	.115
768	-.116	878	.001	988	.079	1,098	.190	1,208	.054	1,318	.130
770	-.100	880	.006	990	.077	1,100	.180	1,210	.060	1,320	.142

TABLE 1 - RUNWAY ELEVATION DATA - RUNWAY 12

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
1,322	0.151	1,432	0.480	1,542	0.472	1,652	0.474	1,762	0.355	1,872	0.259
1,324	.162	1,434	.482	1,544	.475	1,654	.480	1,764	.353	1,874	.264
1,326	.175	1,436	.480	1,546	.475	1,656	.497	1,766	.349	1,876	.256
1,328	.185	1,438	.482	1,548	.474	1,658	.477	1,768	.351	1,878	.260
1,330	.199	1,440	.494	1,550	.459	1,660	.463	1,770	.358	1,880	.258
1,332	.215	1,442	.495	1,552	.459	1,662	.456	1,772	.355	1,882	.255
1,334	.222	1,444	.490	1,554	.464	1,664	.450	1,774	.348	1,884	.252
1,336	.239	1,446	.484	1,556	.459	1,666	.459	1,776	.342	1,886	.245
1,338	.252	1,448	.490	1,558	.452	1,668	.454	1,778	.335	1,888	.240
1,340	.260	1,450	.484	1,560	.442	1,670	.451	1,780	.323	1,890	.236
1,342	.269	1,452	.480	1,562	.445	1,672	.446	1,782	.322	1,892	.235
1,344	.276	1,454	.475	1,564	.447	1,674	.440	1,784	.330	1,894	.232
1,346	.290	1,456	.473	1,566	.449	1,676	.437	1,786	.317	1,896	.229
1,348	.304	1,458	.458	1,568	.435	1,678	.449	1,788	.331	1,898	.227
1,350	.320	1,460	.452	1,570	.423	1,680	.466	1,790	.334	1,900	.225
1,352	.328	1,462	.451	1,572	.439	1,682	.455	1,792	.340	1,902	.215
1,354	.333	1,464	.453	1,574	.454	1,684	.434	1,794	.332	1,904	.228
1,356	.339	1,466	.457	1,576	.459	1,686	.418	1,796	.326	1,906	.213
1,358	.345	1,468	.470	1,578	.453	1,688	.415	1,798	.334	1,908	.196
1,360	.349	1,470	.479	1,580	.443	1,690	.414	1,800	.337	1,910	.189
1,362	.358	1,472	.480	1,582	.451	1,692	.406	1,802	.341	1,912	.190
1,364	.369	1,474	.480	1,584	.452	1,694	.402	1,804	.331	1,914	.198
1,366	.376	1,476	.473	1,586	.452	1,696	.402	1,806	.330	1,916	.203
1,368	.377	1,478	.472	1,588	.442	1,698	.402	1,808	.327	1,918	.210
1,370	.372	1,480	.469	1,590	.442	1,700	.411	1,810	.333	1,920	.214
1,372	.376	1,482	.457	1,592	.441	1,702	.413	1,812	.338	1,922	.210
1,374	.384	1,484	.453	1,594	.434	1,704	.412	1,814	.343	1,924	.208
1,376	.395	1,486	.448	1,596	.427	1,706	.401	1,816	.358	1,926	.200
1,378	.403	1,488	.451	1,598	.431	1,708	.399	1,818	.354	1,928	.196
1,380	.412	1,490	.451	1,600	.434	1,710	.393	1,820	.341	1,930	.195
1,382	.400	1,492	.450	1,602	.444	1,712	.395	1,822	.322	1,932	.195
1,384	.389	1,494	.455	1,604	.454	1,714	.396	1,824	.319	1,934	.181
1,386	.382	1,496	.458	1,606	.473	1,716	.383	1,826	.316	1,936	.180
1,388	.382	1,498	.455	1,608	.462	1,718	.384	1,828	.321	1,938	.191
1,390	.383	1,500	.441	1,610	.461	1,720	.381	1,830	.322	1,940	.198
1,392	.384	1,502	.433	1,612	.461	1,722	.385	1,832	.322	1,942	.183
1,394	.392	1,504	.430	1,614	.462	1,724	.392	1,834	.313	1,944	.171
1,396	.394	1,506	.425	1,616	.474	1,726	.393	1,836	.313	1,946	.169
1,398	.397	1,508	.428	1,618	.467	1,728	.392	1,838	.316	1,948	.172
1,400	.402	1,510	.423	1,620	.472	1,730	.390	1,840	.322	1,950	.174
1,402	.403	1,512	.420	1,622	.470	1,732	.380	1,842	.320	1,952	.181
1,404	.417	1,514	.420	1,624	.463	1,734	.371	1,844	.331	1,954	.166
1,406	.416	1,516	.420	1,626	.472	1,736	.374	1,846	.327	1,956	.163
1,408	.425	1,518	.419	1,628	.470	1,738	.362	1,848	.327	1,958	.172
1,410	.424	1,520	.430	1,630	.470	1,740	.360	1,850	.332	1,960	.166
1,412	.434	1,522	.431	1,632	.474	1,742	.350	1,852	.337	1,962	.172
1,414	.444	1,524	.425	1,634	.482	1,744	.351	1,854	.338	1,964	.172
1,416	.444	1,526	.430	1,636	.492	1,746	.361	1,856	.319	1,966	.166
1,418	.454	1,528	.443	1,638	.482	1,748	.370	1,858	.313	1,968	.172
1,420	.445	1,530	.438	1,640	.474	1,750	.365	1,860	.316	1,970	.166
1,422	.454	1,532	.441	1,642	.457	1,752	.360	1,862	.313	1,972	.171
1,424	.454	1,534	.450	1,644	.452	1,754	.368	1,864	.302	1,974	.170
1,426	.460	1,536	.456	1,646	.460	1,756	.376	1,866	.289	1,976	.155
1,428	.462	1,538	.468	1,648	.468	1,758	.354	1,868	.285	1,978	.154
1,430	.475	1,540	.471	1,650	.476	1,760	.354	1,870	.264	1,980	.161

TABLE 1 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
1,982	0.142	2,092	0.005	2,202	-0.142	2,312	-0.117	2,422	-0.128	2,532	-0.134
1,984	.132	2,094	.003	2,204	-.138	2,314	-.109	2,424	-.125	2,534	-.128
1,986	.122	2,096	-.006	2,206	-.118	2,316	-.110	2,426	-.131	2,536	-.126
1,988	.124	2,098	-.016	2,208	-.122	2,318	-.115	2,428	-.128	2,538	-.132
1,990	.134	2,100	-.024	2,210	-.130	2,320	-.115	2,430	-.130	2,540	-.134
1,992	.129	2,102	-.032	2,212	-.144	2,322	-.117	2,432	-.130	2,542	-.132
1,994	.119	2,104	-.041	2,214	-.152	2,324	-.119	2,434	-.134	2,544	-.124
1,996	.113	2,106	-.038	2,216	-.178	2,326	-.139	2,436	-.128	2,546	-.126
1,998	.115	2,108	-.032	2,218	-.182	2,328	-.140	2,438	-.122	2,548	-.130
2,000	.123	2,110	-.030	2,220	-.188	2,330	-.152	2,440	-.120	2,550	-.135
2,002	.125	2,112	-.034	2,222	-.189	2,332	-.160	2,442	-.118	2,552	-.132
2,004	.120	2,114	-.036	2,224	-.179	2,334	-.166	2,444	-.109	2,554	-.142
2,006	.102	2,116	-.043	2,226	-.198	2,336	-.162	2,446	-.106	2,556	-.145
2,008	.102	2,118	-.039	2,228	-.197	2,338	-.160	2,448	-.118	2,558	-.140
2,010	.102	2,120	-.033	2,230	-.204	2,340	-.159	2,450	-.120	2,560	-.157
2,012	.092	2,122	-.032	2,232	-.209	2,342	-.136	2,452	-.120	2,562	-.152
2,014	.076	2,124	-.046	2,234	-.204	2,344	-.045	2,454	-.138	2,564	-.148
2,016	.071	2,126	-.045	2,236	-.206	2,346	-.175	2,456	-.138	2,566	-.150
2,018	.074	2,128	-.048	2,238	-.189	2,348	-.217	2,458	-.140	2,568	-.149
2,020	.090	2,130	-.050	2,240	-.185	2,350	-.190	2,460	-.141	2,570	-.146
2,022	.092	2,132	-.048	2,242	-.178	2,352	-.168	2,462	-.144	2,572	-.140
2,024	.091	2,134	-.060	2,244	-.216	2,354	-.166	2,464	-.146	2,574	-.137
2,026	.090	2,136	-.057	2,246	-.219	2,356	-.148	2,466	-.148	2,576	-.138
2,028	.080	2,138	-.055	2,248	-.228	2,358	-.146	2,468	-.148	2,578	-.138
2,030	.072	2,140	-.056	2,250	-.222	2,360	-.145	2,470	-.152	2,580	-.139
2,032	.072	2,142	-.048	2,252	-.238	2,362	-.144	2,472	-.157	2,582	-.134
2,034	.071	2,144	-.047	2,254	-.248	2,364	-.145	2,474	-.160	2,584	-.131
2,036	.056	2,146	-.041	2,256	-.277	2,366	-.151	2,476	-.162	2,586	-.129
2,038	.058	2,148	-.047	2,258	-.316	2,368	-.151	2,478	-.162	2,588	-.128
2,040	.053	2,150	-.053	2,260	-.325	2,370	-.156	2,480	-.157	2,590	-.128
2,042	.052	2,152	-.039	2,262	-.342	2,372	-.158	2,482	-.150	2,592	-.128
2,044	.045	2,154	-.038	2,264	-.340	2,374	-.152	2,484	-.141	2,594	-.138
2,046	.045	2,156	-.046	2,266	-.331	2,376	-.144	2,486	-.134	2,596	-.139
2,048	.040	2,158	-.039	2,268	-.340	2,378	-.146	2,488	-.136	2,598	-.147
2,050	.040	2,160	-.037	2,270	-.350	2,380	-.149	2,490	-.138	2,600	-.160
2,052	.036	2,162	-.025	2,272	-.366	2,382	-.151	2,492	-.140	2,602	-.169
2,054	.034	2,164	-.029	2,274	-.386	2,384	-.147	2,494	-.145	2,604	-.184
2,056	.030	2,166	-.051	2,276	-.391	2,386	-.141	2,496	-.141	2,606	-.197
2,058	.005	2,168	-.065	2,278	-.400	2,388	-.139	2,498	-.144	2,608	-.216
2,060	-.009	2,170	-.058	2,280	-.397	2,390	-.139	2,500	-.146	2,610	-.231
2,062	.000	2,172	-.050	2,282	-.391	2,392	-.141	2,502	-.148	2,612	-.248
2,064	.016	2,174	-.061	2,284	-.384	2,394	-.138	2,504	-.146	2,614	-.257
2,066	.018	2,176	-.069	2,286	-.368	2,396	-.138	2,506	-.146	2,616	-.273
2,068	.015	2,178	-.078	2,288	-.352	2,398	-.139	2,508	-.145	2,618	-.286
2,070	.024	2,180	-.072	2,290	-.341	2,400	-.139	2,510	-.144	2,620	-.306
2,072	.032	2,182	-.076	2,292	-.321	2,402	-.138	2,512	-.144	2,622	-.325
2,074	.037	2,184	-.085	2,294	-.295	2,404	-.129	2,514	-.140	2,624	-.324
2,076	.021	2,186	-.095	2,296	-.263	2,406	-.129	2,516	-.146	2,626	-.337
2,078	.018	2,188	-.097	2,298	-.220	2,408	-.125	2,518	-.143	2,628	-.354
2,080	.013	2,190	-.100	2,300	-.186	2,410	-.119	2,520	-.148	2,630	-.367
2,082	.016	2,192	-.111	2,302	-.158	2,412	-.117	2,522	-.148	2,632	-.369
2,084	.011	2,194	-.119	2,304	-.142	2,414	-.124	2,524	-.148	2,634	-.357
2,086	.008	2,196	-.127	2,306	-.132	2,416	-.128	2,526	-.138	2,636	-.338
2,088	.004	2,198	-.124	2,308	-.119	2,418	-.130	2,528	-.140	2,638	-.332
2,090	.004	2,200	-.138	2,310	-.118	2,420	-.128	2,530	-.134	2,640	-.[illegible]

TABLE 1 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
2,642	-0.334	2,702	-0.246	2,762	-0.166	2,822	-0.179	2,882	-0.168	2,942	-0.126
2,644	-.344	2,704	-.242	2,764	-.168	2,824	-.196	2,884	-.170	2,944	-.124
2,646	-.358	2,706	-.239	2,766	-.162	2,826	-.188	2,886	-.168	2,946	-.131
2,648	-.360	2,708	-.235	2,768	-.158	2,828	-.190	2,888	-.160	2,948	-.128
2,650	-.371	2,710	-.225	2,770	-.152	2,830	-.181	2,890	-.149	2,950	-.130
2,652	-.372	2,712	-.214	2,772	-.158	2,832	-.179	2,892	-.147	2,952	-.126
2,654	-.370	2,714	-.201	2,774	-.150	2,834	-.171	2,894	-.148	2,954	-.128
2,656	-.360	2,716	-.185	2,776	-.148	2,836	-.176	2,896	-.145	2,956	-.131
2,658	-.355	2,718	-.185	2,778	-.158	2,838	-.170	2,898	-.154	2,958	-.140
2,660	-.344	2,720	-.174	2,780	-.160	2,840	-.168	2,900	-.143	2,960	-.138
2,662	-.339	2,722	-.148	2,782	-.160	2,842	-.157	2,902	-.127	2,962	-0.134
2,664	-.334	2,724	-.124	2,784	-.158	2,844	-.164	2,904	-.121	2,964	-.140
2,666	-.325	2,726	-.154	2,786	-.158	2,846	-.158	2,906	-.128	2,966	-.136
2,668	-.321	2,728	-.187	2,788	-.151	2,848	-.162	2,908	-.138	2,968	-.124
2,670	-.319	2,730	-.211	2,790	-.146	2,850	-.172	2,910	-.128	2,970	-.128
2,672	-.312	2,732	-.220	2,792	-.148	2,852	-.175	2,912	-.138	2,972	-.124
2,674	-.308	2,734	-.229	2,794	-.150	2,854	-.179	2,914	-.131	2,974	-.128
2,676	-.304	2,736	-.228	2,796	-.151	2,856	-.176	2,916	-.135	2,976	-.126
2,678	-.296	2,738	-.218	2,798	-.144	2,858	-.176	2,918	-.125	2,978	-.124
2,680	-.285	2,740	-.215	2,800	-.151	2,860	-.171	2,920	-.127	2,980	-.118
2,682	-.278	2,742	-.200	2,802	-.167	2,862	-.172	2,922	-.134	2,982	-0.115
2,684	-.273	2,744	-.200	2,804	-.166	2,864	-.171	2,924	-.127	2,984	-.104
2,686	-.261	2,746	-.188	2,806	-.168	2,866	-.168	2,926	-.127	2,986	-.100
2,688	-.252	2,748	-.179	2,808	-.165	2,868	-.170	2,928	-.132	2,988	-.108
2,690	-.257	2,750	-.175	2,810	-.175	2,870	-.160	2,930	-.130	2,990	-.117
2,692	-.249	2,752	-.152	2,812	-.179	2,872	-.155	2,932	-.130	2,992	-.116
2,694	-.250	2,754	-.146	2,814	-.188	2,874	-.131	2,934	-.128	2,994	-.108
2,696	-.249	2,756	-.152	2,816	-.168	2,876	-.130	2,936	-.128	2,996	-.118
2,698	-.250	2,758	-.161	2,818	-.173	2,878	-.135	2,938	-.129	2,998	-.118
2,700	-.250	2,760	-.163	2,820	-.167	2,880	-.162	2,940	-.125	3,000	-.104

TABLE 1 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
0	10.30										
2	10.31	102	10.52	202	10.54	302	10.67	402	10.85	502	10.95
4	10.30	104	10.53	204	10.53	304	10.66	404	10.86	504	10.95
6	10.30	106	10.53	206	10.52	306	10.67	406	10.86	506	10.95
8	10.31	108	10.54	208	10.52	308	10.67	408	10.86	508	10.96
10	10.32	110	10.54	210	10.52	310	10.67	410	10.86	510	10.97
12	10.33	112	10.55	212	10.52	312	10.67	412	10.85	512	10.97
14	10.34	114	10.55	214	10.52	314	10.67	414	10.86	514	10.98
16	10.35	116	10.55	216	10.52	316	10.66	416	10.86	516	10.97
18	10.36	118	10.55	218	10.53	318	10.66	418	10.87	518	10.97
20	10.36	120	10.54	220	10.52	320	10.65	420	10,87	520	10.98
22	10.37	122	10.55	222	10.52	322	10.65	422	10,87	522	10.99
24	10.37	124	10.55	224	10.51	324	10.65	424	10.87	524	11:00
26	10.37	126	10.56	226	10.52	326	10.65	426	10.87	526	11.01
28	10.38	128	10.57	228	10.52	328	10.66	428	10.86	528	11.03
30	10.39	130	10.57	230	10.51	330	10.67	430	10.85	530	11.03
32	10.40	132	10.57	232	10.52	332	10.67	432	10.84	532	11.03
34	10.40	134	10.57	234	10.52	334	10.67	434	10.84	534	11.03
36	10.41	136	10.57	236	10.53	336	10.68	436	10.83	536	11.03
38	10.41	138	10.58	238	10.53	338	10.68	438	10.83	538	11.03
40	10.42	140	10.57	240	10.53	340	10.68	440	10.84	540	11.03
42	10.43	142	10.57	242	10.53	342	10.69	442	10.85	542	11.03
44	10.43	144	10.58	244	10.53	344	10.69	444	10.86	544	11.02
46	10.44	146	10.57	246	10.53	346	10.69	446	10.87	546	11.02
48	10.44	148	10.56	248	10.53	348	10.70	448	10.87	548	11.03
50	10.44	150	10.56	250	10.53	350	10.71	450	10.88	550	11.04
52	10.44	152	10.56	252	10.53	352	10.71	452	10.89	552	11.05
54	10.44	154	10.56	254	10.52	354	10.72	454	10.90	554	11.05
56	10.45	156	10.56	256	10.53	356	10.72	456	10.92	556	11.04
58	10.46	158	10.56	258	10.54	358	10.71	458	10.93	558	11.06
60	10.47	160	10.56	260	10.54	360	10.72	460	10.94	560	11.07
62	10.47	162	10.56	262	10.54	362	10.72	462	10.95	562	11.07
64	10.48	164	10.55	264	10.54	364	10.72	464	10.95	564	11.08
66	10.49	166	10.55	266	10.54	366	10.71	466	10.95	566	11.08
68	10.49	168	10.55	268	10.54	368	10.72	468	10.95	568	11.09
70	10.50	170	10.56	270	10.55	370	10.72	470	10.95	570	11.10
72	10.50	172	10.57	272	10.55	372	10.73	472	10.95	572	11.12
74	10.50	174	10.57	274	10.54	374	10.73	474	10.96	574	11.13
76	10.50	176	10.57	276	10.55	376	10.74	476	10.97	576	11.14
78	10.50	178	10.57	278	10.55	378	10.75	478	10.98	578	11.14
80	10.50	180	10.56	280	10.56	380	10.75	480	10.98	580	11.15
82	10.49	182	10.55	282	10.57	382	10.78	482	10.99	582	11.16
84	10.49	184	10.55	284	10.58	384	10.77	484	10.99	584	11.17
86	10.49	186	10.55	286	10.59	386	10.78	486	10.99	586	11.17
88	10.49	188	10.55	288	10.60	388	10.79	488	11.00	588	11.17
90	10.50	190	10.55	290	10.61	390	10.80	490	11.01	590	11.17
92	10.50	192	10.56	292	10.62	392	10.81	492	11.01	592	11.17
94	10.51	194	10.56	294	10.63	394	10.81	494	11.01	594	11.18
96	10.51	196	10.56	296	10.65	396	10.82	496	11.01	596	11.18
98	10.52	198	10.56	298	10.66	398	10.83	498	11.98	598	11.18
100	10.52	200	10.55	300	10.66	400	10.84	500	10.96	600	11.17

TABLE 2 - RUNWAY ELEVATION DATA - RUNWAY 28R

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
602	11.17	702	11.03	602	11.07	902	11.05	1002	11.11	1102	11.32
604	11.17	704	11.02	804	11.06	904	11.06	1004	11.10	1104	11.32
606	11.17	706	11.01	806	11.07	906	11.06	1006	11.11	1106	11.31
608	11.19	708	11.00	808	11.08	908	11.06	1008	11.11	1108	11.31
610	11.17	710	10.99	810	11.08	910	11.07	1010	11.12	1110	11.31
612	11.18	712	10.99	812	11.08	912	11.07	1012	11.12	1112	11.32
614	11.18	714	10.98	814	11.09	914	11.07	1014	11.12	1114	11.31
616	11.18	716	10.99	816	11.09	916	11.07	1016	11.11	1116	11.32
618	11.19	718	10.98	818	11.08	918	11.07	1018	11.11	1118	11.33
620	11.19	720	10.98	820	11.08	920	11.08	1020	11.12	1120	11.34
622	11.19	722	10.98	822	11.08	922	11.08	1022	11.11	1122	11.35
624	11.20	724	10.98	824	11.08	924	11.07	1024	11.11	1124	11.35
626	11.21	726	10.98	826	11.08	926	11.07	1026	11.11	1126	11.36
628	11.21	728	10.98	828	11.08	928	11.07	1028	11.10	1128	11.36
630	11.21	730	10.99	830	11.07	930	11.06	1030	11.10	1130	11.36
632	11.20	732	10.99	832	11.08	932	11.06	1032	11.12	1132	11.37
634	11.20	734	11.00	834	11.08	934	11.06	1034	11.13	1134	11.37
636	11.20	736	11.00	836	11.08	936	11.06	1036	11.15	1136	11.37
638	11.19	738	11.00	838	11.08	938	11.06	1038	11.16	1138	11.37
640	11.18	740	11.00	840	11.09	940	11.07	1040	11.17	1140	11.38
642	11.18	742	11.00	842	11.08	942	11.07	1042	11.18	1142	11.38
644	11.17	744	11.01	844	11.08	944	11.08	1044	11.18	1144	11.38
646	11.16	746	11.02	846	11.07	946	11.08	1046	11.19	1146	11.38
648	11.15	748	11.02	848	11.07	948	11.09	1048	11.19	1148	11.38
650	11.14	750	11.02	850	11.06	950	11.09	1050	11.20	1150	11.38
652	11.14	752	11.02	852	11.05	952	11.09	1052	11.22	1152	11.38
654	11.14	754	11.02	854	11.05	954	11.09	1054	11.22	1154	11.38
656	11.12	756	11.02	856	11.04	956	11.10	1056	11.23	1156	11.38
658	11.11	758	11.01	858	11.05	958	11.09	1058	11.23	1158	11.37
660	11.09	760	11.01	860	11.04	960	11.09	1060	11.23	1160	11.37
662	11.09	762	11.00	862	11.04	962	11.09	1062	11.24	1162	11.37
664	11.09	764	11.00	864	11.04	964	11.09	1064	11.25	1164	11.37
666	11.09	766	11.00	866	11.04	966	11.08	1066	11.25	1166	11.38
668	11.09	768	11.00	868	11.04	968	11.08	1068	11.26	1168	11.38
670	11.09	770	11.00	870	11.04	970	11.07	1070	11.24	1170	11.39
672	11.09	772	11.00	872	11.04	972	11.07	1072	11.27	1172	11.38
674	11.09	774	10.99	874	11.03	974	11.06	1074	11.28	1174	11.38
676	11.09	776	10.99	876	11.03	976	11.07	1076	11.28	1176	11.39
678	11.09	778	10.98	878	11.03	978	11.09	1078	11.30	1178	11.40
680	11.09	780	10.99	880	11.03	980	11.10	1080	11.31	1180	11.41
682	11.09	782	10.99	882	11.02	982	11.10	1082	11.32	1182	11.41
684	11.09	784	11.00	884	11.02	984	11.11	1084	11.33	1184	11.42
686	11.08	786	11.01	886	11.02	986	11.11	1086	11.34	1186	11.43
688	11.08	788	11.01	888	11.02	988	11.12	1088	11.34	1188	11.44
690	11.08	790	11.01	890	11.02	990	11.12	1090	11.34	1190	11.44
692	11.08	792	11.03	892	11.02	992	11.12	1092	11.34	1192	11.45
694	11.07	794	11.04	894	11.03	994	11.11	1094	11.33	1194	11.46
696	11.06	796	11.03	896	11.03	996	11.11	1096	11.32	1196	11.46
698	11.05	798	11.05	898	11.04	998	11.11	1098	11.32	1198	11.46
700	11.04	800	11.06	900	11.05	1000	11.11	1100	11.31	1200	11.46

TABLE 2 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
1202	11.47	1302	11.52	1402	11.47	1502	11.25	1602	10.92	1702	10.88
1204	11.48	1304	11.52	1404	11.47	1504	11.24	1604	10.92	1704	10.87
1206	11.48	1306	11.52	1406	11.48	1506	11.23	1606	10.91	1706	10.88
1208	11.48	1308	11.52	1408	11.47	1508	11.22	1608	10.91	1708	10.87
1210	11.49	1310	11.52	1410	11.46	1510	11.21	1610	10.91	1710	10.87
1212	11.50	1312	11.52	1412	11.46	1512	11.19	1612	10.91	1712	10.87
1214	11.50	1314	11.52	1414	11.46	1514	11.18	1614	10.90	1714	10.87
1216	11.50	1316	11.53	1416	11.46	1516	11.17	1616	10.89	1716	10.86
1218	11.50	1318	11.52	1418	11.46	1518	11.17	1618	10.88	1718	10.85
1220	11.50	1320	11.52	1420	11.47	1520	11.15	1620	10.97	1720	10.84
1222	11.50	1322	11.52	1422	11.47	1522	11.13	1622	10.89	1722	10.84
1224	11.49	1324	11.53	1424	11.47	1524	11.12	1624	10.88	1724	10.84
1226	11.49	1326	11.53	1426	11.46	1526	11.10	1626	10.88	1726	10.84
1228	11.49	1328	11.53	1428	11.46	1528	11.10	1628	10.88	1728	10.84
1230	11.48	1330	11.53	1430	11.44	1530	11.18	1630	10.87	1730	10.83
1232	11.47	1332	11.53	1432	11.43	1532	11.17	1632	10.86	1732	10.82
1234	11.46	1334	11.53	1434	11.41	1534	11.14	1634	10.85	1734	10.82
1236	11.46	1336	11.54	1436	11.40	1536	11.14	1636	10.86	1736	10.82
1238	11.48	1338	11.53	1438	11.39	1538	11.12	1638	10.86	1738	10.82
1240	11.46	1340	11.52	1440	11.38	1540	11.00	1640	10.85	1740	10.82
1242	11.47	1342	11.52	1442	11.37	1542	10.97	1642	10.85	1742	10.82
1244	11.47	1344	11.51	1444	11.36	1544	10.95	1644	10.85	1744	10.83
1246	11.47	1346	11.53	1446	11.36	1546	10.94	1646	10.84	1746	10.82
1248	11.47	1348	11.52	1448	11.35	1548	10.92	1648	10.84	1748	10.83
1250	11.46	1350	11.54	1450	11.35	1550	10.91	1650	10.84	1750	10.82
1252	11.45	1352	11.53	1452	11.35	1552	10.92	1652	10.83	1752	10.82
1254	11.45	1354	11.54	1454	11.35	1554	10.92	1654	10.83	1754	10.82
1256	11.45	1356	11.53	1456	11.35	1556	10.91	1656	10.82	1756	10.82
1258	11.46	1358	11.54	1458	11.34	1558	10.93	1658	10.82	1758	10.81
1260	11.46	1360	11.53	1460	11.34	1560	10.93	1660	10.81	1760	10.81
1262	11.46	1362	11.54	1462	11.33	1562	10.93	1662	10.81	1762	10.81
1264	11.45	1364	11.55	1464	11.32	1564	10.93	1664	10.80	1764	10.81
1266	11.45	1366	11.54	1466	11.32	1566	10.93	1666	10.79	1766	10.82
1268	11.45	1368	11.54	1468	11.32	1568	10.93	1668	10.79	1768	10.82
1270	11.45	1370	11.54	1470	11.31	1570	10.93	1670	10.79	1770	10.82
1272	11.45	1372	11.54	1472	11.31	1572	10.93	1672	10.79	1772	10.83
1274	11.46	1374	11.53	1474	11.30	1574	10.93	1674	10.79	1774	10.83
1276	11.46	1376	11.52	1476	11.29	1576	10.93	1676	10.79	1776	10.83
1278	11.46	1378	11.51	1478	11.29	1578	10.93	1678	10.80	1778	10.84
1280	11.48	1380	11.50	1480	11.28	1580	10.94	1680	10.80	1780	10.84
1282	11.47	1382	11.49	1482	11.28	1582	10.94	1682	10.81	1782	10.85
1284	11.47	1384	11.49	1484	11.28	1584	10.94	1684	10.82	1784	10.86
1286	11.48	1386	11.49	1486	11.28	1586	10.94	1686	10.82	1786	10.86
1288	11.48	1388	11.49	1488	11.28	1588	10.95	1688	10.83	1788	10.86
1290	11.48	1390	11.49	1490	11.27	1590	10.94	1690	10.84	1790	10.88
1292	11.48	1392	11.48	1492	11.27	1592	10.93	1692	10.85	1792	10.87
1294	11.49	1394	11.47	1494	11.27	1594	10.94	1694	10.85	1794	10.88
1296	11.49	1396	11.47	1496	11.26	1596	10.94	1696	10.85	1796	10.88
1298	11.50	1398	11.47	1498	11.26	1598	10.93	1698	10.87	1798	10.86
1300	11.51	1400	11.46	1500	11.25	1600	10.92	1700	10.88	1800	10.87

TABLE 2 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
1802	10.87	1902	10.90	2002	10.87	2102	10.88	2202	10.85	2302	11.09
1804	10.86	1904	10.91	2004	10.88	2104	10.88	2204	10.85	2304	11.10
1806	10.85	1906	10.91	2006	10.88	2106	10.88	2206	10.85	2306	11.10
1808	10.85	1908	10.91	2008	10.88	2108	10.89	2208	10.86	2308	11.11
1810	10.89	1910	10.91	2010	10.88	2110	10.89	2210	10.86	2310	11.12
1812	10.91	1912	10.91	2012	10.88	2112	10.90	2212	10.86	2312	11.14
1814	10.91	1914	10.91	2014	10.89	2114	10.91	2214	10.87	2314	11.14
1816	10.92	1916	10.91	2016	10.90	2116	10.92	2216	10.88	2316	11.15
1818	10.92	1918	10.90	2018	10.89	2118	10.92	2218	10.88	2318	11.16
1820	10.93	1920	10.90	2020	10.89	2120	10.93	2220	10.89	2320	11.16
1822	10.93	1922	10.89	2022	10.89	2122	10.92	2222	10.90	2322	11.16
1824	10.93	1924	10.90	2024	10.89	2124	10.92	2224	10.91	2324	11.15
1826	10.94	1926	10.90	2026	10.90	2126	10.92	2226	10.91	2326	11.15
1828	10.94	1928	10.90	2028	10.89	2128	10.92	2228	10.92	2328	11.16
1830	10.95	1930	10.91	2030	10.89	2130	10.92	2230	10.92	2330	11.15
1832	10.94	1932	10.90	2032	10.88	2132	10.92	2232	10.93	2332	11.14
1834	10.93	1934	10.91	2034	10.87	2134	10.92	2234	10.94	2334	11.14
1836	10.93	1936	10.89	2036	10.88	2136	10.93	2236	10.94	2336	11.14
1838	10.92	1938	10.89	2038	10.87	2138	10.93	2238	10.95	2338	11.14
1840	10.93	1940	10.89	2040	10.87	2140	10.93	2240	10.96	2340	11.14
1842	10.91	1942	10.89	2042	10.87	2142	10.93	2242	10.96	2342	11.14
1844	10.91	1944	10.89	2044	10.87	2144	10.93	2244	10.97	2344	11.15
1846	10.90	1946	10.88	2046	10.88	2146	10.94	2246	10.99	2346	11.15
1848	10.90	1948	10.88	2048	10.88	2148	10.93	2248	10.99	2348	11.15
1850	10.90	1950	10.87	2050	10.88	2150	10.93	2250	10.99	2350	11.15
1852	10.91	1952	10.87	2052	10.88	2152	10.93	2252	10.99	2352	11.15
1854	10.91	1954	10.87	2054	10.88	2154	10.93	2254	11.00	2354	11.15
1856	10.89	1956	10.86	2056	10.88	2156	10.93	2256	11.00	2356	11.16
1858	10.90	1958	10.88	2058	10.89	2158	10.92	2258	11.00	2358	11.16
1860	10.91	1960	10.87	2060	10.89	2160	10.92	2260	11.01	2360	11.15
1862	10.91	1962	10.86	2062	10.89	2162	10.91	2262	11.01	2362	11.15
1864	10.91	1964	10.87	2064	10.89	2164	10.90	2264	11.02	2364	11.16
1866	10.92	1966	10.87	2066	10.89	2166	10.92	2266	11.02	2366	11.16
1868	10.93	1968	10.86	2068	10.89	2168	10.91	2268	11.02	2368	11.16
1870	10.94	1970	10.85	2070	10.89	2170	10.91	2270	11.04	2370	11.16
1872	10.94	1972	10.85	2072	10.88	2172	10.90	2272	11.05	2372	11.16
1874	10.94	1974	10.85	2074	10.88	2174	10.90	2274	11.05	2374	11.16
1876	10.94	1976	10.86	2076	10.89	2176	10.90	2276	11.06	2376	11.16
1878	10.94	1978	10.85	2078	10.88	2178	10.88	2278	11.06	2378	11.16
1880	10.95	1980	10.86	2080	10.89	2180	10.88	2280	11.05	2380	11.17
1882	10.93	1982	10.86	2082	10.88	2182	10.86	2282	11.04	2382	11.17
1884	10.93	1984	10.86	2084	10.88	2184	10.85	2284	11.03	2384	11.17
1886	10.93	1986	10.87	2086	10.88	2186	10.85	2286	11.03	2386	11.17
1888	10.93	1988	10.87	2088	10.88	2188	10.84	2288	11.02	2388	11.17
1890	10.92	1990	10.87	2090	10.88	2190	10.84	2290	11.03	2390	11.17
1892	10.93	1992	10.87	2092	10.87	2192	10.84	2292	11.03	2392	11.17
1894	10.93	1994	10.87	2094	10.87	2194	10.84	2294	11.04	2394	11.16
1896	10.93	1996	10.88	2096	10.87	2196	10.85	2296	11.05	2396	11.15
1898	10.93	1998	10.87	2098	10.87	2198	10.85	2298	11.06	2398	11.15
1900	10.91	2000	10.88	2100	10.87	2200	10.85	2300	11.07	2400	11.14

TABLE 2 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
2402	11.14	2502	11.30	2602	11.35	2702	11.51	2802	11.54	2902	11.61
2404	11.14	2504	11.30	2604	11.35	2704	11.52	2804	11.55	2904	11.61
2406	11.13	2506	11.31	2606	11.35	2706	11.52	2806	11.55	2906	11.62
2408	11.12	2508	11.31	2608	11.35	2708	11.52	2808	11.55	2908	11.63
2410	11.12	2510	11.32	2610	11.35	2710	11.52	2810	11.56	2910	11.64
2412	11.12	2512	11.32	2612	11.36	2712	11.52	2812	11.55	2912	11.65
2414	11.12	2514	11.33	2614	11.36	2714	11.52	2814	11.55	2914	11.66
2416	11.12	2516	11.33	2616	11.36	2716	11.52	2816	11.55	2916	11.67
2418	11.12	2518	11.34	2618	11.35	2718	11.52	2818	11.55	2918	11.67
2420	11.13	2520	11.35	2620	11.35	2720	11.52	2820	11.54	2920	11.67
2422	11.13	2522	11.35	2622	11.35	2722	11.52	2822	11.53	2922	11.68
2424	11.14	2524	11.35	2624	11.35	2724	11.51	2824	11.53	2924	11.70
2426	11.15	2526	11.35	2626	11.35	2726	11.51	2826	11.53	2926	11.72
2428	11.16	2528	11.35	2628	11.35	2728	11.51	2828	11.51	2928	11.73
2430	11.17	2530	11.35	2630	11.36	2730	11.50	2830	11.52	2930	11.74
2432	11.18	2532	11.36	2632	11.36	2732	11.50	2832	11.52	2932	11.76
2434	11.19	2534	11.36	2634	11.36	2734	11.50	2834	11.53	2934	11.77
2436	11.20	2536	11.35	2636	11.36	2736	11.50	2836	11.53	2936	11.78
2438	11.20	2538	11.35	2638	11.36	2738	11.51	2838	11.54	2938	11.80
2440	11.22	2540	11.35	2640	11.37	2740	11.51	2840	11.55	2940	11.82
2442	11.23	2542	11.35	2642	11.38	2742	11.51	2842	11.56	2942	11.82
2444	11.24	2544	11.35	2644	11.38	2744	11.52	2844	11.56	2944	11.82
2446	11.24	2546	11.35	2646	11.39	2746	11.52	2846	11.57	2946	11.83
2448	11.25	2548	11.34	2648	11.39	2748	11.52	2848	11.57	2948	11.82
2450	11.26	2550	11.34	2650	11.40	2750	11.52	2850	11.57	2950	11.82
2452	11.27	2552	11.34	2652	11.41	2752	11.53	2852	11.58	2952	11.83
2454	11.28	2554	11.34	2654	11.42	2754	11.53	2854	11.58	2954	11.84
2456	11.28	2556	11.35	2656	11.42	2756	11.53	2856	11.58	2956	11.83
2458	11.29	2558	11.35	2658	11.43	2758	11.52	2858	11.58	2958	11.83
2460	11.30	2560	11.35	2660	11.43	2760	11.52	2860	11.58	2960	11.83
2462	11.30	2562	11.34	2662	11.42	2762	11.52	2862	11.58	2962	11.83
2464	11.30	2564	11.33	2664	11.42	2764	11.52	2864	11.59	2964	11.83
2466	11.31	2566	11.33	2666	11.43	2766	11.52	2866	11.59	2966	11.83
2468	11.30	2568	11.33	2668	11.43	2768	11.52	2868	11.59	2968	11.84
2470	11.31	2570	11.33	2670	11.43	2770	11.53	2870	11.59	2970	11.85
2472	11.31	2572	11.33	2672	11.43	2772	11.53	2872	11.58	2972	11.86
2474	11.31	2574	11.33	2674	11.43	2774	11.53	2874	11.57	2974	11.87
2476	11.31	2576	11.33	2676	11.43	2776	11.54	2876	11.57	2976	11.88
2478	11.30	2578	11.32	2678	11.44	2778	11.53	2878	11.58	2978	11.86
2480	11.30	2580	11.33	2680	11.44	2780	11.53	2880	11.57	2980	11.89
2482	11.30	2582	11.33	2682	11.45	2782	11.54	2882	11.57	2982	11.90
2484	11.29	2584	11.33	2684	11.46	2784	11.54	2884	11.57	2984	11.90
2486	11.29	2586	11.33	2686	11.46	2786	11.54	2886	11.58	2986	11.90
2488	11.29	2588	11.33	2688	11.47	2788	11.54	2888	11.58	2988	11.90
2490	11.29	2590	11.34	2690	11.48	2790	11.53	2890	11.59	2990	11.90
2492	11.29	2592	11.34	2692	11.48	2792	11.53	2892	11.60	2992	11.90
2494	11.29	2594	11.34	2694	11.49	2794	11.53	2894	11.62	2994	11.91
2496	11.29	2596	11.35	2696	11.49	2796	11.53	2896	11.61	2996	11.91
2498	11.29	2598	11.35	2698	11.50	2798	11.54	2898	11.61	2998	11.90
2500	11.29	2600	11.35	2700	11.50	2800	11.54	2900	11.61	3000	11.91

TABLE 2 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
3002	11.91	3102	11.94	3202	11.92	3302	11.84	3402	11.87	3502	12.08
3004	11.91	3104	11.93	3204	11.95	3304	11.84	3404	11.88	3504	12.08
3006	11.91	3106	11.92	3206	11.95	3306	11.84	3406	11.89	3506	12.08
3008	11.90	3108	11.92	3208	11.95	3308	11.84	3408	11.89	3508	12.08
3010	11.91	3110	11.92	3210	11.94	3310	11.84	3410	11.89	3510	12.08
3012	11.91	3112	11.92	3212	11.94	3312	11.84	3412	11.91	3512	12.09
3014	11.92	3114	11.92	3214	11.93	3314	11.84	3414	11.91	3514	12.10
3016	11.92	3116	11.92	3216	11.92	3316	11.84	3416	11.92	3516	12.10
3018	11.92	3118	11.92	3218	11.92	3318	11.84	3418	11.93	3518	12.10
3020	11.92	3120	11.92	3220	11.91	3320	11.84	3420	11.95	3520	12.10
3022	11.92	3122	11.92	3222	11.90	3322	11.83	3422	11.95	3522	12.10
3024	11.92	3124	11.92	3224	11.90	3324	11.83	3424	11.96	3524	12.11
3026	11.92	3126	11.92	3226	11.89	3326	11.83	3426	11.96	3526	12.11
3028	11.91	3128	11.91	3228	11.88	3328	11.82	3428	11.96	3528	12.12
3030	11.91	3130	11.90	3230	11.87	3330	11.83	3430	11.96	3530	12.13
3032	11.92	3132	11.90	3232	11.86	3332	11.83	3432	11.95	3532	12.13
3034	11.91	3134	11.90	3234	11.85	3334	11.83	3434	11.96	3534	12.13
3036	11.91	3136	11.90	3236	11.84	3336	11.82	3436	11.96	3536	12.13
3038	11.91	3138	11.90	3238	11.84	3338	11.82	3438	11.96	3538	12.14
3040	11.91	3140	11.90	3240	11.84	3340	11.83	3440	11.96	3540	12.14
3042	11.90	3142	11.90	3242	11.83	3342	11.82	3442	11.95	3542	12.13
3044	11.90	3144	11.90	3244	11.82	3344	11.83	3444	11.95	3544	12.13
3046	11.90	3146	11.90	3246	11.82	3346	11.83	3446	11.94	3546	12.13
3048	11.90	3148	11.90	3248	11.81	3348	11.84	3448	11.96	3548	12.11
3050	11.90	3150	11.90	3250	11.83	3350	11.84	3450	11.98	3550	12.10
3052	11.90	3152	11.90	3252	11.83	3352	11.83	3452	11.99	3552	12.07
3054	11.90	3154	11.90	3254	11.83	3354	11.83	3454	12.01	3554	12.06
3056	11.90	3156	11.90	3256	11.84	3356	11.83	3456	12.03	3556	12.07
3058	11.90	3158	11.90	3258	11.84	3358	11.83	3458	12.04	3558	12.08
3060	11.90	3160	11.90	3260	11.84	3360	11.83	3460	12.05	3560	12.09
3062	11.91	3162	11.89	3262	11.84	3362	11.84	3462	12.05	3562	12.10
3064	11.92	3164	11.88	3264	11.82	3364	11.84	3464	12.05	3564	12.11
3066	11.92	3166	11.88	3266	11.83	3366	11.84	3466	12.05	3566	12.11
3068	11.92	3168	11.87	3268	11.82	3368	11.85	3468	12.05	3568	12.12
3070	11.93	3170	11.87	3270	11.83	3370	11.85	3470	12.05	3570	12.06
3072	11.93	3172	11.86	3272	11.83	3372	11.85	3472	12.04	3572	12.01
3074	11.93	3174	11.86	3274	11.84	3374	11.85	3474	12.06	3574	12.03
3076	11.93	3176	11.85	3276	11.84	3376	11.84	3476	12.06	3576	12.04
3078	11.94	3178	11.85	3278	11.84	3378	11.84	3478	12.07	3578	12.05
3080	11.94	3180	11.84	3280	11.85	3380	11.85	3480	12.07	3580	12.05
3082	11.95	3182	11.84	3282	11.84	3382	11.85	3482	12.07	3582	12.06
3084	11.95	3184	11.84	3284	11.84	3384	11.86	3484	12.07	3584	12.06
3086	11.95	3186	11.84	3286	11.84	3386	11.86	3486	12.06	3586	12.05
3088	11.96	3188	11.84	3288	11.85	3388	11.87	3488	12.07	3588	12.04
3090	11.96	3190	11.85	3290	11.85	3390	11.87	3490	12.07	3590	12.03
3092	11.96	3192	11.87	3292	11.85	3392	11.87	3492	12.08	3592	12.02
3094	11.96	3194	11.89	3294	11.86	3394	11.87	3494	12.08	3594	12.02
3096	11.96	3196	11.89	3296	11.86	3396	11.87	3496	12.08	3596	12.02
3098	11.96	3198	11.90	3298	11.84	3398	11.86	3498	12.09	3598	12.02
3100	11.95	3200	11.89	3300	11.84	3400	11.87	3500	12.09	3600	12.01

TABLE 2 (Cont'd)

Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft	Distance along runway, ft	Runway elevation, ft
3602	11.99	3702	11.94	3602	12.16
3604	11.98	3704	11.95	3604	12.17
3606	11.94	3706	11.95	3806	12.17
3608	11.94	3708	11.95	3808	12.17
3610	11.93	3710	11.95	3810	12.15
3612	11.93	3712	11.95	3812	12.14
2614	11.92	3714	11.96	3814	12.13
3616	11.91	3716	11.95	3816	12.12
3618	11.90	3718	11.95	3818	12.11
3620	11.90	3720	11.96	3820	12.10
3622	11.90	3722	11.97	3822	12.09
3624	11.90	3724	11.98	3824	12.09
3626	11.90	3726	11.98	3826	12.09
3628	11.91	3728	11.99	3828	12.08
3630	11.90	3730	12.00	3830	12.07
3632	11.88	3732	12.00	3832	12.07
3634	11.87	3734	11.99	3834	12.06
3636	11.87	3736	11.99	3836	12.05
3638	11.86	3738	11.99	3838	12.03
3640	11.86	3740	12.00	3840	12.03
3642	11.85	3742	12.00	3842	12.02
3644	11.86	3744	12.01	3844	12.01
3646	11.86	3746	12.02	3846	12.02
3648	11.85	3748	12.02	3848	12.01
3650	11.85	3750	12.03	3850	12.01
3652	11.85	3752	12.04	3852	12.01
3654	11.86	3754	12.05	3854	12.01
3656	11.86	3756	12.06	3856	12.02
3658	11.87	3758	12.06	3858	12.02
3660	11.86	3760	12.06	3860	12.01
3662	11.86	3762	12.06	3862	12.00
3664	11.85	3764	12.06	3864	12.00
3666	11.84	3766	12.06	3866	11.98
3668	11.85	3768	12.06	3868	11.97
3670	11.85	3770	12.06	3870	11.97
3672	11.87	3772	12.07	3872	11.96
3674	11.89	3774	12.08	3874	11.96
3676	11.88	3776	12.09	3876	11.96
3678	11.88	3778	12.10	3878	11.96
3680	11.88	3780	12.09	3880	11.95
3682	11.89	3782	12.12		
3684	11.90	3784	12.13		
3686	11.91	3786	12.14		
3688	11.91	3788	12.13		
3690	11.91	3790	12.14		
3692	11.91	3792	12.14		
3694	11.92	3794	12.14		
3696	11.92	3796	12.15		
3698	11.93	3798	12.15		
3700	11.94	3800	12.16		

TABLE 2 (Cont'd)

		Case A*			Case B*		
		Peak	Mean	Mean Square	Peak	Mean	Mean Square
X	1	.6384E 01	.5729E-01	.9529E 01	.6972E 01	.5190E 01	.9628E 01
	2	.6514E 01	.3635E-01	.9673E 01	.6263E 01	-.6430E-02	.9684E 01
	3	.7404E 01	-.1184E-00	.1019E 02	.7066E 01	-.1283E-00	.9941E 01
	4	.1328E-01	.2913E-03	.1934E-04	.1169E-01	.3660E-03	.8872E-05
	5	.2199E 02	-.2990E-01	.2861E 02			
	6	.1475E 01	.8761E-03	.1435E-00			
	7	.3542E-00	-.9928E-03	.9513E-02			
	8	.1126E 01	.2813E-02	.8512E-01			
	9	.4480E-00	-.7574E-03	.9970E-02			
	10	.3381E-00	-.6679E-03	.5949E-02			
$\dot{X}$	1	.2750E 02	.1644E-00	.2763E 02	.5490E 02	.1569E-00	.3209E 02
	2	.3073E 02	.1178E-00	.2676E 02	.3909E 02	.1206E-00	.3653E 02
	3	.2488E 02	.1581E-00	.4333E 02	.4163E 02	.1589E-00	.6385E 02
	4	.6385E-01	.2855E-04	.4354E-03	.7548E-01	.6479E-04	.2058E-03
	5	.1715E 03	-.1094E-00	.1318E 04			
	6	.2038E 02	-.7565E-02	.2708E 02			
	7	.3614E 01	-.2086E-03	.1040E 01			
	8	.1757E 02	.3524E-02	.1266E 02			
	9	.9888E 01	.1058E-02	.3882E 01			
	10	.1192E 02	.3098E-02	.3184E 01			
$\ddot{X}$	1	.3516E 04	.3593E-00	.3882E 05	.4960E 04	.1444E-00	.5377E 05
	2	.4913E 04	.8251E-02	.3372E 05	.3354E 04	.2479E-00	.2747E 05
	3	.2202E 03	.3174E-00	.2645E 04	.3331E 03	.1531E-00	.4186E 04
	4	.3570E-00	.1240E-02	.1192E-01	.4347E-00	-.5184E-03	.7819E-02
	5	.1389E 04	.8123E-01	.9404E 05			
	6	.3111E 03	-.6157E-01	.6930E 04			
	7	.8496E 02	.1916E-01	.4770E 03			
	8	.7044E 03	-.1572E-00	.9336E 04			
	9	.3393E 03	.1038E-00	.5193E 04			
	10	.6743E 03	.5940E-01	.8863E 04			
U_p		.9638E 01	.3441E-00	.1438E 02	.9935E 01	.4120E-00	.1310E 02
$\dot{U}_p$		.3788E 02	.1324E-00	.1401E 03	.5524E 02	.1087E-00	.1509E 03
$\ddot{U}_p$		.5263E 03	-.7451E 00	.9549E 04	.4009E 03	.5549E 00	.7623E 04
F_t	1	.1922E 06	.3646E 03	.2153E 10	.2844E 06	.1555E 03	.2755E 10
	2	.3211E 05	.9340E 02	.7608E 08	.4149E 05	-.2862E 03	.7226E 08

TABLE 3 - PEAK, MEAN AND MEAN SQUARE VALUES OF RESPONSE
BOEING 707 ON RUNWAY 12**

* Case A refers to the case when all 6 flexural modes are considered, and Case B refers to the case when only rigid body modes are considered.

** All lengths are in inches and time in seconds

		Case A*			Case B*		
		Peak	Mean	Mean Square	Peak	Mean	Mean Square
X	1	.6735E 01	.5458E-01	.9831E 01	.7410E 01	.5575E-01	.1029E 02
	2	.1474E 02	-.4364E-00	.1704E 02	.1165E 02	-.2231E-00	.1525E 02
	3	.7950E 01	-.2348E-00	.1106E 02	.7828E 01	-.3179E-00	.1121E 02
	4	.3180E-01	.1720E-02	.4661E-04	.2547E-01	.1890E-02	.4015E-04
	5	.8648E 01	-.6262E-02	.5044E 01			
	6	.7590E 01	-.1733E-02	.3137E 01			
	7	.2585E-00	-.1272E-03	.2646E-02			
	8	.6691E 00	.1996E-04	.2120E-01			
	9	.5295E 00	.2079E-04	.1443E-01			
	10	.1113E 01	.2571E-03	.8636E-01			
$\dot{X}$	1	.3690E 02	.8984E-01	.3828E 02	.5434E 02	.1528E-00	.7315E 02
	2	.6783E 02	.2365E-00	.1533E 03	.5990E 02	-.6439E-01	.1672E 03
	3	.3378E 02	.1285E-01	.1078E 03	.4722E 02	.1233E-00	.1519E 03
	4	.6223E-01	-.3453E-03	.2436E-03	.6286E-01	.6046E-03	.3274E-03
	5	.7755E 02	-.2011E-00	.3286E 03			
	6	.6500E 02	-.4480E-01	.2258E 03			
	7	.3276E 01	-.8260E-02	.5269E 00			
	8	.7602E 01	-.4501E-02	.1932E 01			
	9	.7232E 01	.4386E-02	.1726E 01			
	10	.1899E 02	.2527E-01	.1564E 02			
$\ddot{X}$	1	.5902E 04	.1178E-00	.6854E 05	.5139E 04	.1526E-01	.7660E 05
	2	.6225E 04	-.1695E-00	.9563E 05	.6536E 04	-.4592E-00	.9545E 05
	3	.2899E 03	.3244E-01	.5354E 04	.4077E 03	-.1739E-00	.9278E 04
	4	.2517E-00	.7613E-04	.2662E-02	.3307E-00	.1368E-02	.4656E-02
	5	.9306E 03	.8015E 00	.3330E 05			
	6	.9012E 03	-.7782E-01	.3968E 05			
	7	.6754E 02	.4347E-01	.2634E 03			
	8	.1661E 03	-.9492E-01	.8057E 03			
	9	.2091E 03	-.2689E-01	.1147E 04			
	10	.5739E 03	-.1853E-00	.1629E 05			
U_p		.3094E 02	.2124E 01	.5504E 02	.2732E 02	.2391E 01	.5401E 02
$\dot{U}_p$		.9835E 02	.3214E-00	.5843E 03	.8107E 02	-.5399E 00	.5747E 03
$\ddot{U}_p$		.9147E 03	-.6565E-01	.4227E 05	.4908E 03	-.1675E 01	.1656E 05
F_t	1	.2506E 06	.5062E 02	.4574E 10	.3810E 06	.1635E 03	.8490E 10
	2	.6824E 05	.1679E 02	.1989E 09	.7990E 05	.3393E 03	.3179E 09

TABLE 4 - PEAK, MEAN AND MEAN SQUARE VALUES OF RESPONSE

BOEING 733 94 ON RUNWAY 12**

* Case A refers to the case when all 6 flexural modes are considered, and Case B refers to the case when only rigid body modes are considered.

** All lengths are in inches and time in seconds

APPENDIX 1

COMPUTER PROGRAMS

```
*********************************
*     PROGRAM NAME-PROFILE      *
*********************************
C     MAIN PROGRAM
C     THE MAIN PROGRAM INTERPOLATES,ACCORDING TO THE DATA READ IN,
C     THE VELOCITY,THETA1,THETA2,AND THE RUNWAY ELEVATIONS AT THE MAIN
C     AND THE NOSE LANDING GEARS AT EACH INSTANT OF TIME
*     LABEL
*     LIST
*     FORTRAN
CMAIN
      DIMENSION XT(50),DT(50),N1(50),AN1(50),V1(50),X1(2500),V(2500),
     1XD(50),N2(50),AN2(50),DEL1(7000),X1DEL(2500),X2DEL(2500),
     2THETA1(2500),THETA2(2500),THE1(50),THE2(50),TH1(50),TH2(50)
      COMMON XT,DT,N1,AN1,V1,X1,V,XD,N2,AN2,DEL1,X1DEL,X2DEL,THETA1,
     1THETA2,THE1,THE2,TH1,TH2,NC,LP,LPP,KP1,NP,NT,ND,NF1,NF2,NP1,NF11,
     2NF21,A1,A2,A1A2,NE,MP,INE,K,J,IT,I1,I2,L1,L2,T,XL1,XL2,XI1,XI2,
     3X1M1,VM1,XI3,NN3,XL3,N22,J1,XJ1,J12,J11,DSLOPE,X2,LSS,IS,XIS,M,
     4TX,ACC,TSLOP1,TSLOP2,KP,MX,IB,KT,IE,XX,XXS,NCC,JP
      CALL XRP
      CALL XIN
      NT=NT
      XK=DT(NT)/10.0
      L1=L1
      I2=I2
      I1=I1
      L2=L2
      M=M
      IS=IS
      LSS=LSS
    2 J=M-(IT-2400)
      T=T+DT(I1)
      TX=T-XL1
      ACC=(V1(L1+1)-V1(L1))/XT(L1)
      V(J)=ACC*TX+V1(L1)
      TSLOP1=(THE1(L1+1)-THE1(L1))/TH1(L1)
      TSLOP2=(THE2(L1+1)-THE2(L1))/TH2(L1)
      THETA1(J)=TSLOP1*TX+(THE1(L1)
      THETA2(J)=TSLOP2*TX+(THE2(L1)
      X1(J)=X1M1+VM1*DT(I1)+(ACC/2.0)*DT(I1)**2
      X2=X1(J)+A1A2
      GOTO1000
 1001 IF(T-(XL1+XT(L1)-XK))10,11,11
   11 XL1=XL1+XT(L1)
      L1=L1+1
      T=T-DT(I1)
      PRINT 150,T,XL1,XT(L1),XK,M
  150 FORMAT(4F14.6,I5)
      IF(M-MP)2,14,14
   10 IF(T-(XI1-XK))13,12,12
   12 IF(I1-NT)6,14,14
    6 I1=I1+1
      XI1=XI1+DT(I1)*AN1(I1)
      PRINT 151,T,XI1,I1,XK,M
  151 FORMAT(2F14.6,I5,F14.6,I5)
   13 M=M+1
      J=J+1
      X1M1=X1(J-1)
      VM1=V(J-1)
      IF(M-IT)2,2,18

   14 KP=0
      MX=M+2400-IT
      GOTO17
   18 KP=1
      MX=2400
   17 CALL XPRINT
      IF(KP)21,21,22
   21 IF(LP-1)23,23,24
   24 CALL EOF(5)
      CALL REWUNL(5)
   23 CALL EXIT
   22 IT=IT+2400
      X1M1=X1(2400)
      VM1=V(2400)
      GOTO2
 1000 XX=X1(J)-XL2
      SLOPE1=(DEL1(L2+1)-DEL1(L2))/XD(I2)
      X1DEL(J)=SLOPE1*XX+DEL1(L2)
      IF(X1(J)-(XL2+XD(I2)))100,100,110
  110 XL2=XL2+XD(I2)
      L2=L2+1
      GOTO1000
  100 IF(X1(J)-XI2)130,130,120
  120 I2=I2+1
      XI2=XI2+XD(I2)*AN2(I2)
      GOTO1000
  130 CONTINUE
 1100 XXS=X2-XL3
      SLOPES=(DEL1(LSS+1)-DEL1(LSS))/XD(IS)
      X2DEL(J)=SLOPES*XXS+DEL1(LSS)
      IF(X2-(XL3+XD(IS)))701,701,710
  710 XL3=XL3+XD(IS)
      LSS=LSS+1
      GOTO1100
  701 IF(X2-XIS)730,730,720
  720 IF(IS-ND)721,14,14
  721 IS=IS+1
      XIS=XIS+XD(IS)*AN2(IS)
      GOTO 1100
  730 GOTO1001
      END

++++++++++++++++++++++++++
+     SUBROUTINE XPR      +
++++++++++++++++++++++++++
C     THE SUBROUTINE XRP READ IN CONTROL DATA,TIME HISTORY OF VELOCITY,
C     THETA1,THETA2 AND THE RUNWAY ELEVATION AND PRINTS OUT THESE DATA
*     LABEL
*     LIST
*     FORTRAN
CSUBXRP
      SUBROUTINE XRP
      DIMENSION XT(50),DT(50),N1(50),AN1(50),V1(50),X1(2500),V(2500),
     1XD(50),N2(50),AN2(50),DEL1(7000),X1DEL(2500),X2DEL(2500),
     2THETA1(2500),THETA2(2500),THE1(50),THE2(50),TH1(50),TH2(50)
      COMMON XT,DT,N1,AN1,V1,X1,V,XD,N2,AN2,DEL1,X1DEL,X2DEL,THETA1,
     1THETA2,THE1,THE2,TH1,TH2,NC,LP,LPP,KP1,NP,NT,ND,NF1,NF2,NP1,NF11,
     2NF21,A1,A2,A1A2,NE,MP,INE,K,J,IT,I1,I2,L1,L2,T,XL1,XL2,XI1,XI2,
     3X1M1,VM1,XI3,NN3,XL3,N22,J1,XJ1,J12,J11,DSLOPE,X2,LSS,IS,XIS,M,
     4TX,ACC,TSLOP1,TSLOP2,KP,MX,IB,KT,IE,XX,XXS,NCC,JP
      READ 203,DP
      READ 202 ,JP
      READ 202,NC,NCC,LP,LPP,KP1,NP,N1,ND,NF1,NF2
      NP1=NP+1
      READ202,(N1(I),I=1,NT)
      READ202,(N2(I),I=1,ND)
      READ203,(DT(I),I=1,NT)
      READ203,(XT(I),I=1,NP)
      READ 203,(V1(I),I=1,NP1)
      READ203,(XD(I),I=1,ND)
      NF11=NF1+1
      NF21=NF2+1
      READ 203,(THE1(I),I=1,NF11)
      READ 203,(THE2(I),I=1,NF21)
      READ203,(TH1(I),I=1,NF1)
      READ 203,(TH2(I),I=1,NF2)
      READ203,A1,A2
      NE=1
      DO250 I=1,ND
  250 NE=NF+N2(I)
      READ 204,(DEL1(I),I=1,NE)
  202 FORMAT(10I7)
  203 FORMAT(5F14.6)
  204 FORMAT(8F9.4)
      DO 10 I=1,NE
   10 DEL1(I)=DEL1(I)*DP
      MP=1
      DO251 I=1,NT
  251 MP=MP+N1(I)
      PRINT 236,NC
  236 FORMAT(7H RUNWAY,I5)
      PRINT 237,NCC
  237 FORMAT(9H AIRPLANE,I5)
      PRINT 300,JP
  300 FORMAT(6X2HJP,I5)
      PRINT 210,LP
  210 FORMAT(6X2HLP,I5)
      PRINT211,LPP
  211 FORMAT(5X3HLPP,I5)
      PRINT 212,KP1
  212 FORMAT(5X3HKP1,I5)
      PRINT213,NP
  213 FORMAT(6X2HNP,I5)
      PRINT214,NT
  214 FORMAT(6X2HNT,I5)
      PRINT215,ND
  215 FORMAT(6X2HND,I5)
      PRINT 230,NF1
  230 FORMAT(5X3HNF1,I5)
      PRINT 231,NF2
  231 FORMAT(5X3HNF2,I5)
      PRINT216,MP
  216 FORMAT(6X2HMP,I5)
      PRINT 217,(N1(I),I=1,NT)
  217 FORMAT(6X2HN1,20I5/8X,20I5/8X,20I5)
      PRINT 218,(N2(I),I=1,ND)
  218 FORMAT(6X2HN2,20I5/8X,20I5/8X,20I5)
      PRINT 232,(TH1(I),I=1,NF1)

  232 FORMAT(5X3HTH1,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E1)
     14)
      PRINT233,(TH2(I),I=1,NF2)
  233 FORMAT(5X3HTH2,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E1)
     14)
      PRINT 219,(DT(I),I=1,NT)
  219 FORMAT(6X2HDT,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E11.4)
      PRINT 220,(XT(I),I=1,NP)
  220 FORMAT(6X2HXT,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E11.4)
      PRINT 221,(V1(I),I=1,NP1)
  221 FORMAT(6X2HV1,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E11.4)
      PRINT 222,(XD(I),I=1,ND)
  222 FORMAT(6X2HXD,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E11.4)
      PRINT 23X,(THE1(I),I=1,NF11)
  234 FORMAT(4X4HTHE1,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E
     111.4)
      PRINT 235,(THE2(I),I=1,NF21)
  235 FORMAT(4X4HTHE2,10E11.4/8X,10E11.4/8X,10E11.4/8X,10E
     111.4)
      PRINT223,A1
  223 FORMAT(6X2HA1,E11.4)
      PRINT224,A2
  224 FORMAT(6X2HA2,E11.4)
      PRINT225
  225 FORMAT(1H1)
      PRINT226
  226 FORMAT(4X4HDEL1)
      INE=(NE-1)/10+1
      DO227 I=1,INE
      K=(I-1)*10+1
      IE1=K+9
      IF(IE1-NE)227,228,228
  228 IE1=NE
  227 PRINT 229,K,(DEL1(J),J=K,IE1)
  229 FORMAT(I7,10E11.4)
      A1A2=A1+A2
      IF(LP-1)954,954,951
  951 WRITE TAPE 5,NC,NCC,MP,NT,JP
      WRITE TAPE 5,(N1(I),I=1,NT)
      WRITE TAPE 5,(DT(I),I=1,NT)
  954 RETURN
      END

++++++++++++++++++++++++++
+     SUBROUTINE XIN      +
++++++++++++++++++++++++++
C     THE SUBROUTINE XIN INITIALIZES THE INTERPOLATION PARAMETERS
*     LABEL
*     FORTRAN
*     LIST
CSUBXIN
      SUBROUTINE XIN
      DIMENSION XT(50),DT(50),N1(50),AN1(50),V1(50),X1(2500),V(2500),
     1XD(50),N2(50),AN2(50),DEL1(7000),X1DEL(2500),X2DEL(2500),
     2THETA1(2500),THETA2(2500),THE1(50),THE2(50),TH1(50),TH2(50)
      COMMON XT,DT,N1,AN1,V1,X1,V,XD,N2,AN2,DEL1,X1DEL,X2DEL,THETA1,
     1THETA2,THE1,THE2,TH1,TH2,NC,LP,LPP,KP1,NP,NT,ND,NF1,NF2,NP1,NF11,
     2NF21,A1,A2,A1A2,NE,MP,INE,K,J,IT,I1,I2,L1,L2,T,XL1,XL2,XI1,XI2,
```

```
     3X1M1,VM1,XI3,NN3,XL3,N22,J1,XJ1,J12,J11,DSLOPE,X2,LSS,IS,XIS,M,
     4TX,ACC,TSLOP1,TSLOP2,KP,MX,IB,KT,IE,XX,XXS,NCC,JP
      IT=2400
      I1=1
      I2=1
      L1=1
      L2=1
      T=0.0
      XL1=0.0
      XL2=0.0
      DO1 I=1,NT
    1 AN1(I)=N1(I)
      DO3 I=1,ND
    3 AN2(I)=N2(I)
      X1=AN1(1)*DT(1)
      X12=AN2(1)*XD(1)
      V(1)=V1(1)
      X1(1)=0.0
      X1M1=X1(1)
      VM1=V(1)
      THETA1(1)=THE1(1)
      THETA2(1)=THE2(1)
      X1DEL(1)=DEL1(1)
      XI3=0.0
      NN3=0
      XL3=0.0
      DO 612 J=1,ND
      N22=N2(J)
      DO611 J1=1,N22
      XJ1=J1
      IF(A1A2-(XJ1*XD(J)+XI3))610,610,611
  610 J12=J1+1+NN3
      J11=J1+NN3
      DSLOPE=(DEL1(J12)-DEL1(J11))/XD(J)
      X2DEL(1)=DSLOPE*(A1A2-((XJ1-1.0)*XD(J)+XI3))+DEL1(J11)
      GOTO700
  611 XL3=XL3+XD(J)
      NN3=NN3+N2(J)
      XI3=XI3+AN2(J)*XD(J)
  612 CONTINUE
  700 X2=A1A2
      LSS=J1+NN3
      IS=J
      XIS=XI3+AN2(J)*XD(J)
      M=2
      RETURN
      END

++++++++++++++++++++++++++++
+     SUBROUTINE XPRINT     +
++++++++++++++++++++++++++++
C     THE SUBROUTINE XPRINT PRINTS OUT THE RESULTS OF INTERPOLATION
C     AND TRANSFERS THEM ONTO TAPE
*     LABEL
*     FORTRAN
*     LIST
CSUBXPRINT
      SUBROUTINE XPRINT
      DIMENSION XT(50),DT(50),N1(50),AN1(50),V1(50),X1(2500),V(2500),
     1XD(50),N2(50),AN2(50),DEL1(7000),X1DEL(2500),X2DEL(2500),
     2THETA1(2500),THETA2(2500),THE1(50),THE2(50),TH1(50),TH2(50)
      COMMON XT,DT,N1,AN1,V1,X1,V,XD,N2,AN2,DEL1,X1DEL,X2DEL,THETA1,
     1THETA2,THE1,THE2,TH1,TH2,NC,LP,LPP,KP1,NP,NT,ND,NF1,NF2,NP1,NF11,
     2NF21,A1,A2,A1A2,NE,MP,INE,K,J,I1,I1,I2,L1,L2,I,XL1,XL2,XI1,XI2,
     3X1M1,VM1,XI3,NN3,XL3,N22,J1,XJ1,J12,J11,DSLOPE,X2,LSS,IS,XIS,M,
     4TX,ACC,TSLOP1,TSLOP2,KP,MX,IB,KT,IE,XX,XXS,NCC,JP
      IF(LP-1)50,50,18
   18 JQ=JP
      NQ=(MX-1)/JP+1
      DO 19 I=1,NQ
      IF(I-NQ)101,100,101
  100 JQ=MX-(JP*(NQ-1))
  101 JN=(I-1)*JP+1
      JNN=(I-1)*JP+JQ
      WRITETAPE5,((V(J),THETA1(J),THETA2(J),X1DEL(J),X2DEL(J)),J=JN,JNN)
   19 CONTINUE
      IF(LPP-1)50,50,51
   50 PRINT 225
      PRINT 150
      IB=(MX-1)/(10*KP1)+1
      DO 151 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)151,152,152
  152 IE=MX
  151 PRINT 160,KT,(V(J),J=K,IE,KP1)
      PRINT 225
      PRINT 170
      DO 161 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)161,162,162
  162 IE=MX
  161 PRINT 160,KT,(X1(J),J=K,IE,KP1)
      PRINT 225
      PRINT 180
      DO 191 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)191,192,192
  192 IE=MX
  191 PRINT 160,KT,(X1DEL(J),J=K,IE,KP1)
      PRINT 225
      PRINT 181
      DO 891 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)891,892,892
  892 IE=MX
  891 PRINT 160,KT,(X2DEL(J),J=K,IE,KP1)
      PRINT 225
      PRINT182
      DO 901 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)901,902,902
  902 IE=MX
  901 PRINT 160,KT,(THETA1(J),J=K,IE,KP1)
      PRINT 225
      PRINT 183
      DO 903 I=1,IB
      K=(I-1)*KP1*10+1
      KT=K+(IT-2400)
      IE=K+9*KP1
      IF(IE-MX)903,904,904
  904 IE=MX
  903 PRINT 160,KT,(THETA2(J),J=K,IE,KP1)
   51 RETURN
  150 FORMAT(7X1HV)
  160 FORMAT(I5,3X,10E11.4)
  170 FORMAT(7X1HX)
  180 FORMAT(3X5HX1DEL)
  181 FORMAT(3X5HX2DEL)
  182 FORMAT(2X6HTHETA1)
  183 FORMAT(2X6HTHETA2)
  225 FORMAT (1H1)
      END
```

```
*********************************
*      PROGRAM NAME-RESPONSE     *
*********************************
C      THE PROGRAM RESPONSE COMPUTES THE RESPONSE OF AIRPLANE
C      OPERATING ON RUNWAY
C      MAIN PROGRAM
C      THE MAIN PROGRAM MAINLY DETERMINES,AT THE BEGINNING OF EACH CYCLE,
C      WHICH SUBROUTINE SHOULD BE USED TO CALCULATE THE RESPONSE OF THE
C      AIRPLANE DEPENDING ON WHETHER THE LANDING GEAR(OR GEARS) IS
C      LOCKED OR UNLOCKED
*      LABEL
*      FORTRAN
*      LIST
CMAIN
       DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
      1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2,200),Z0(2,200),S(2,200),
      2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),U1(2,200),
      3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),X(3),
      4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
      5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
      6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
      7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
      8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
      9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
       DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
      1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
      2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
      3XMC4I(12,12),XXKT(2)
       COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
      1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
      2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
      3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
      4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
      5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
      6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
      7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
      8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
       CALL XREAD
       CALL XPRINT
       CALL MASS
       FSST1=FS(1,1)
       FSST2=FS(2,1)
       IF(KWW-1)850,850,851
  850 WRITE TAPE 6,NC,NCC,JP,MP1,NT,NMODE
       WRITE TAPE 6,(N1(K),K=1,NT)
       WRITE TAPE 6,(DT(K),K=1,NT)
  851 IT=IT1
       IL=JP
       I=1
       NX=N1(1)
  705 CALL XRP
       IF(IL-2*JP)811,810,811
  810 JY=2
       GOTO812
  811 JY=1
  812 DO300 J=JY,JXX
       J1=J
       M=J+(IL-2*JP)
       M1=M
       IF(M-NX)800,800,801
  801 I=I+1
       NX=NX+N1(I)
  800 CONTINUE
       DO3K=1,NMODE
       XA(K)=Z1IN(K)+(DT(1)/2.0)*Z3IN(K)
     3 XB(K)=ZIN(K)+DT(I)*Z1IN(K)+((DT(I)**2./3.0)*Z3IN(K)
       XL(1,J1)=(XL11+XL12*(THETA(1,J1)+ZIN(4)))*V(J1)**2
       XL(2,J1)=(XL21+XL22*(THETA(2,J1)+ZIN(4)))*V(J1)**2
       IF(U1IN(1)-Z1IN(1))120,10,110
   10 IF(U1IN(2)-Z1IN(2))100,30,90
   30 IF(FIN(1)-F1(1))50,40,40
   40 IF(FIN(2)-F1(2))42,41,41
   41 DO11 K=1,2
   11 F(K,J1)=F1(K)
       CALL C1
       DO12 K=1,2
       U4(K)=U1(K,J1)
   12 Z4(K)=Z1(K,J1)
       CALL B1
       GOTO200
   42 IF(FIN(2)+F1(2))43,43,44
   43 F(1,J1)=F1(1)
       F(2,J1)=-F1(2)
        CALL C1
       U4(1)=U1(1,J1)
       Z4(1)=Z1(1,J1)
       U4(2)=Z1(2,J1)
       Z4(2)=U1(2,J1)
       CALL B1
       GOTO200
   44 F(1,J1)=F1(1)
       KZ=1
       KZZ=2
       KPP=1
       CALL C34
       U4(1)=U1(1,J1)
       Z4(1)=Z1(1,J1)
       KX1=1
       KX2=2
       KDD=1
       CALL B23
       GOTO200
   50 IF(FIN(1)+F1(1))60,60,70
   60 IF(FIN(2)-F1(2))62,61,61
   61 F(1,J1)=-F1(1)
       F(2,J1)=F1(2)
       CALL C1
       U4(1)=Z1(1,J1)
       Z4(1)=U1(1,J1)
       U4(2)=U1(2,J1)
       Z4(2)=Z1(2,J1)
       CALL B1
       GOTO200
   62 IF(FIN(2)+F1(2))63,63,64
   63 DO13 K=1,2
   13 F(K,J1)=-F1(K)
       CALL C1
       DO 14 K=1,2
       U4(K)=Z1(K,J1)
   14 Z4(K)=U1(K,J1)
       CALL B1
       GOTO200
   64 F(1,J1)=-F1(1)
       KZ=1
       KZZ=2
       KPP=1
       CALL C34
       U4(1)=Z1(1,J1)
       Z4(1)=U1(1,J1)
       KX1=1
       KX2=2
       KDD=1
       CALL B23
       GOTO200
   70 IF(FIN(2)-F1(2))72,71,71
   71 F(2,J1)=F1(2)
       KZ=2
       KZZ=1
       KPP=2
       CALL C34
       U4(2)=U1(2,J1)
       Z4(2)=Z1(2,J1)
       KX1=2
       KX2=1
       KDD=2
       CALL B23
       GOTO200
   72 IF(FIN(2)+F1(2))73,73,74
   73 F(2,J1)=-F1(2)
       KZ=2
       KZZ=1
       KPP=2
       CALL C34
       U4(2)=Z1(2,J1)
       Z4(2)=U1(2,J1)
       KX1=2
       KX2=1
       KDD=2
       CALL B23
       GOTO200
   74 CALL C2
       CALL XA3
       GOTO200
   90 IF(FIN(1)-F1(1))92,61,61
   92 IF(FIN(1)+F1(1))61,61,71
  100 IF(FIN(1)-F1(1))102,43,43
  102 IF(FIN(1)+F1(1))63,63,73
  110 IF(U1IN(2)-Z1IN(2))43,40,41
  120 IF(U1IN(2)-Z1IN(2))63,60,61
  200 DO201 K=1,NMODE
       ZIN(K)=Z(K,J)
       Z1IN(K)=Z1(K,J)
       Z2IN(K)=Z2(K,J)
  201 Z3IN(K)=Z3(K,J)
       DO202 K=1,2
       UIN(K)=U(K,J)
       U1IN(K)=U1(K,J)
       U2IN(K)=U2(K,J)
       U3IN(K)=U3(K,J)
       SIN(K)=S(K,J)
       S1IN(K)=S1(K,J)
       S2IN(K)=S2(K,J)
       FIN(K)=F(K,J)
       FSIN(K)=FS(K,J)
       FSTIN(K)=FST(K,J)
       FDIN(K)=FD(K,J)
  202 ZOIN(K)=Z0(K,J)
  300 CONTINUE
       IF(KWW-1)600,600,601
  600 CALL PW(JXX,IL,NMODE,Z,Z1,Z2,Z3,FST)
  601 IF(KWW-1)602,602,204
  602 CALL XPRINT
  204 IF(IL-JP1-MP1)705,2000,2000
 2000 IF(KWW-1)2001,2001,2002
 2001 CALL PUT(6)
       CALL REWUNL(6)
 2002 IF(KJ-1)2003,2004,2003
 2003 CALL REWUNL(5)
 2004 CALL EXIT
       END
***************************
*      SUBROUTINE XREAD    *
***************************
C      READ IN CONTROL DATA,AIRPLANE CHARACTERISTICS AND INITIAL
C      CONDITIONS
*      LABEL
*      FORTRAN
*      LIST
CXREAD
       SUBROUTINE XREAD ,
       DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
      1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
      2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),U1(2,200),
      3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),X(3),
      4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
      5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
      6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
      7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
      8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
      9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
       DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
      1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
      2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
      3XMC4I(12,12),XXKT(2)
       COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
      1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
      2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
      3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
      4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
      5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
      6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
      7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
      8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
       READ 502,LP,KW,KWW,KJ
  502 FORMAT(16I5)
       IF(KJ-1)601,600,601
```

```
  600 READ 502,NC,NCC,MP,NT
      READ 502,(N1(I),I=1,NT)
      READ 508,(DT(I),I=1,NT)
      GOTO 603
  601 READ TAPE 5,NC,NCC,MP,NT,JP
      READ TAPE 5,(N1(I),I=1,NT)
      READ TAPE 5,(DT(I),I=1,NT)
  603 PRINT 501,NC
  501 FORMAT(7H RUNWAY,I5)
      PRINT 503,NCC
  503 FORMAT(9H AIRPLANE,I5)
      READ 502,MP1,IT1,KP1
      IF(MP-MP1) 505,506,506
  505 PRINT 507
      CALL EXIT
  507 FORMAT(22HMP1 IS GREATER THAN MP)
  506 READ508,G,(W(I),I=1,3)
  508 FORMAT(5F14.6)
      READ 502,NMODE,NPT
      NM=NMODE-1
      READ 508,(XM(J),J=1,NMODE)
      READ 518,XM(4)
  518 FORMAT(E16.8)
      READ508,XLAMDA
      READ508,(OMEGA(I),I=1,NMODE)
      DO 510 I=1,NMODE
  510 XC(I)=2.0*XLAMDA*XM(I)*OMEGA(I)
      DO 515 J=1,NPT
  515 READ508,(FE(I,J),I=1,NMODE)
      READ508,(UST(I),ZST(I),I=1,2)
      DO 511 I=1,2
  511 XST(I)=UST(I)-ZST(I)
      READ508,(SMAX(I),I=1,2)
      READ508,(XKT(I),F1(I),I=1,2)
      READ508,XL11,XL12,XL21,XL22
      READ 502,(NFS(I),I=1,2)
      NFS1=NFS(1)
      NFS2=NFS(2)
      NFS11=NFS1+1
      NFS21=NFS2+1
      READ508,(XFS(1,J),J=1,NFS11)
      READ508,(XFS(2,J),J=1,NFS21)
      READ508,(DS(1,J),J=1,NFS1)
      READ508,(DS(2,J),J=1,NFS2)
      READ 502,(NGS(I),I=1,2)
      NGS1=NGS(1)
      NGS2=NGS(2)
      NGS11=NGS1+1
      NGS21=NGS2+1
      READ508,(XG(1,J),J=1,NGS11)
      READ508,(XG(2,J),J=1,NGS21)
      READ508,(DG(1,J),J=1,NGS1)
      READ508,(DG(2,J),J=1,NGS2)
      DO 520I=1,NMODE
  520 READ 508,Z(I,1),Z1(I,1),Z2(I,1),Z3(I,1)
      DO 512 I=1,2
      U(I,1)=0.0
      U1(I,1)=0.0
      U2(I,1)=0.0
      U3(I,1)=0.0
      DO 512 J=3,NMODE
      U(I,1)=Z(J,1)*FE(J,I)+U(I,1)
      U1(I,1)=Z1(J,1)*FE(J,I)+U1(I,1)
      U2(I,1)=Z2(J,1)*FE(J,I)+U2(I,1)
  512 U3(I,1)=Z3(J,1)*FE(J,I)+U3(I,1)
      DO 513 I=1,2
      S(I,1)=U(I,1)-Z(I,1)+XST(I)
      S1(I,1)=U1(I,1)-Z1(I,1)
  513 S2(I,1)=U2(I,1)-Z2(I,1)
      DO521I=1,2
  521 READ 508,F(I,1),ZO(I,1),FS(I,1),FST(I,1),FD(I,1)
      DO100 I=1,NMODE
      ZIN(I)=Z(I,1)
      Z1IN(I)=Z1(I,1)
      Z2IN(I)=Z2(I,1)
  100 Z3IN(I)=Z3(I,1)
      DO101 I=1,2
      UIN(I)=U(I,1)
      U1IN(I)=U1(I,1)
      U2IN(I)=U2(I,1)
      U3IN(I)=U3(I,1)
      SIN(I)=S(I,1)
      S1IN(I)=S1(I,1)
      S2IN(I)=S2(I,1)
      FIN(I)=F(I,1)
      FSTIN(I)=FST(I,1)
      ZOIN(I)=ZO(I,1)
      FSIN(I)=FS(I,1)
  101 FDIN(I)=FD(I,1)
      RETURN
      END
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+     SUBROUTINE XRP     +
++++++++++++++++++++++++
C     READ IN FROM TAPE AND PRINTS INTERPOLATED TIME HISTORY OF AIRPLANE
C     VELOCITY,THETA1,THETA2 AND RUNWAY ELEVATIONS AT THE MAIN AND
C     NOSE GEARS
*     LABEL
*     FORTRAN
*     LIST
CXRP
      SUBROUTINE XRP
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),ZO(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,ZO,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      PRINT 520
  520 FORMAT(3X2HMP,3X2HNT,2X3HIT1,2X3HKP1)
      PRINT 521,MP,NT,IT1,KP1
  521 FORMAT(2O15)
      PRINT 522
  522 FORMAT(3X2HN1)
      PRINT 521,(N1(I),I=1,NT)
      PRINT 523
      1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
      2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
      3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
      4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
      5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
      6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
      7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
      8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      IF(IL-IT)715,715,720
  715 IF(IL-MP1)725,725,730
  725 JXX=JP
      GOTO710
  730 JXX=MP1-(IL-JP)
      GOTO710
  720 IF(IL-MP1)740,740,750
  750 JXX=MP1-IT
      IT=IT+IT1
      GOTO 710
  740 JXX=JP
      IT=IT+IT1
      GOTO 710
  770 PRINT 771
  771 FORMAT(1H1)
      PRINT 772
  772 FORMAT(7X1HV)
      NW=1
      DO791 N=1,JXX
  791 Q(1,N)=VIN)
      NB=(JXX-1)/(10*KP1)+1
  798 DO779 N=1,NB
      ND=(N-1)*KP1*10+1
      NF=ND+(IL-JP*2)
      NY=ND+9*KP1
      IF(NY-JXX)773,774,774
  774 NY=JXX
  773 PRINT 775,NF,(Q(1,NZ),NZ=ND,NY,KP1)
      GOTO(900,901,902,903,799),NW
  900 PRINT 776
  776 FORMAT(2X6HDELTA1)
      DO792 N=1,JXX
  792 Q(1,N)=DELTA(1,N)
      NW=2
      GOTO798
  901 PRINT 779
  779 FORMAT(2X6HDELTA2)
      DO793N=1,JXX
  793 Q(1,N)=DELTA(2,N)
      NW=3
      GOTO798
  902 PRINT 782
  782 FORMAT(2X6HTHETA1)
      DO794 N=1,JXX
  794 Q(1,N)=THETA(1,N)
      NW=4
      GOTO798
  903 PRINT 783
  783 FORMAT(2X6HTHETA2)
      DO795 N=1,JXX
  795 Q(1,N)=THETA(2,N)
      NW=5
      GOTO798
  775 FORMAT(18,10E11.4)
  710 IF(KJ-1)801,800,801
  800 READ 802,(V(N),N=1,JXX)
      READ 802,(THETA(1,N),N=1,JXX)
      READ 802,(THETA(2,N),N=1,JXX)
      READ 802,(DELTA(1,N),N=1,JXX)
      READ 802,(DELTA(2,N),N=1,JXX)
      IL=IL+JP
      GOTO 770
  801 READ TAPE 5,(V(N),THETA(1,N),THETA(2,N),DELTA(1,N),DELTA(2,N),
     1N=1,JXX)
      IL=IL+JP
      GOTO770
  802 FORMAT(5F14.6)
  799 RETURN
      END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE XPRINT     +
++++++++++++++++++++++++++
C     PRINT OUT DATA READ IN VIA SUBROUTINE XREAD
*     LABEL
*     FORTRAN
*     LIST
CXPRINT
      SUBROUTINE XPRINT
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),ZO(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,ZO,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
      1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
      2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
      3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
      4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
      5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
      6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
      7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
      8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      PRINT 520
  520 FORMAT(3X2HMP,3X2HNT,2X3HIT1,2X3HKP1)
      PRINT 521,MP,NT,IT1,KP1
  521 FORMAT(2O15)
      PRINT 522
  522 FORMAT(3X2HN1)
      PRINT 521,(N1(I),I=1,NT)
      PRINT 523
```

```
523 FORMAT(3X2HDT)
    PRINT 524,(DT(I),I=1,NT)
524 FORMAT(9E13.5)
    PRINT 525
525 FORMAT(2X5HMP1,3X2HJP,2X8HNPTNMODE)
    PRINT 521,MP1,JP,NPT,NMODE
    PRINT 526
526 FORMAT(6X1HG,10X6HXLAMDA,8X4HW(1),9X4HW(2),9X4HW(3))
    PRINT 524,G,XLAMDA,(W(I),I=1,3)
    PRINT 527
527 FORMAT(5X2HXM)
    PRINT 524,(XM(I),I=1,NMODE)
    PRINT 528
528 FORMAT(5X2HXC)
    PRINT 524,(XC(I),I=1,NMODE)
    PRINT 529
529 FORMAT(3X5HOMEGA)
    PRINT 524,(OMEGA(I),I=1,NMODE)
    PRINT 530
530 FORMAT(5X2HFE)
    DO 531 J=1,NPT
531 PRINT 524,(FE(I,J),I=1,NMODE)
    PRINT 532
532 FORMAT(4X3HUST,10X3HZST,10X3HXST,10X4HSMAX,9X3HXKT)
    DO 533 I=1,2
533 PRINT 524,UST(I),ZST(I),XST(I),SMAX(I),XKT(I)
    PRINT 534
534 FORMAT(4X4HXL11,9X4HXL12,9X4HXL21,9X4HXL22)
    PRINT 524,XL11,XL12,XL21,XL22
    PRINT 535
535 FORMAT(3X3HNFS)
    PRINT 521,(NFS(I),I=1,2)
    PRINT 536
536 FORMAT(3X8HXFS(1, ))
    PRINT 524,(XFS(1,I),I=1,NFS11)
    PRINT 537
537 FORMAT(3X8HXFS(2, ))
    PRINT 524,(XFS(2,I),I=1,NFS21)
    PRINT 538
538 FORMAT(3X7HDS(1, ))
    PRINT524,(DS(1,I),I=1,NFS1)
    PRINT539
539 FORMAT(3X7HDS(2, ))
    PRINT524,(DS(2,I),I=1,NFS2)
    PRINT540
540 FORMAT(3X3HNGS)
    PRINT521,(NGS(I),I=1,2)
    PRINT541
541 FORMAT(3X7HXG(1, ))
    PRINT524,(XG(1,I),I=1,NGS11)
    PRINT542
542 FORMAT(3X7HXG(2, ))
    PRINT524,(XG(2,I),I=1,NGS21)
    PRINT543
543 FORMAT(3X7HDG(1, ))
    PRINT524,(DG(1,I),I=1,NGS1)
    PRINT544
544 FORMAT(3X7HDG(2, ))
    PRINT524,(DG(2,I),I=1,NGS2)
    PRINT545
545 FORMAT(6X1HZ,11X2HZ1,11X2HZ2,11X2HZ3)
    DO 546 I=1,NMODE
546 PRINT 524,Z(I,1),Z1(I,1),Z2(I,1),Z3(I,1)
    PRINT547
547 FORMAT(6X1HU,11X2HU1,11X2HU2,11X2HU3)
    DO 548 I=1,2
548 PRINT524,U(I,1),U1(I,1),U2(I,1),U3(I,1)
    PRINT549
549 FORMAT(6X1HF,11X2HZO,11X2HFS,10X3HFST,11X2HFD)
    DO550 I=1,2
550 PRINT 524,F(I,1),ZO(I,1),FS(I,1),FST(I,1),FD(I,1)
    RETURN
    END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE YPRINT   +
++++++++++++++++++++++++++
C     PRINT OUT RESPONSE
*     LABEL
*     FORTRAN
*     LIST
CYPRINT
      SUBROUTINE YPRINT
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),ZO(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),O(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,ZO,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      DO10 J=1,JXX
      M=J+(IL-2*JP)
      PRINT 1,M
    1 FORMAT(3X2HM=,I5)
      PRINT 2
    2 FORMAT(5X2HZ ,12X2HZ1,12X2HZ2,12X2HZ3)
      DO4K=1,NMODE
    4 PRINT 3,Z(K,J),Z1(K,J),Z2(K,J),Z3(K,J)
    3 FORMAT(8E14.6)
      PRINT 5
    5 FORMAT(5X2HU ,12X2HU1,12X2HU2,12X2HU3,12X3HFST,11X2HFS,11X2HFD,
     112X2HF )
      DO6K=1,2
    6 PRINT 3,U(K,J),U1(K,J),U2(K,J),U3(K,J),FST(K,J),FS(K,J),FD(K,J),
     1F(K,J)
   10 CONTINUE
      RETURN
      END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE YWT      +
++++++++++++++++++++++++++
C     TRANSFER RESPONSE OF AIRPLANE TO TAPE
*     LABEL
*     FORTRAN
*     LIST
CYWT
      SUBROUTINE YWT(JXX,IL,NMODE,Z,Z1,Z2,Z3,FST)
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),FST(2,200)
      WRITE TAPE 6,((Z(K,K1),K1=1,JXX),K=1,NMODE)
      WRITE TAPE 6,((Z1(K,K1),K1=1,JXX),K=1,NMODE)
      WRITE TAPE 6,((Z2(K,K1),K1=1,JXX),K=1,NMODE)
      WRITE TAPE 6,((Z3(K,K1),K1=1,JXX),K=1,NMODE)
      WRITE TAPE 6, ((FST(K,K1),K1=1,JXX),K=1,2)
      RETURN
      END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE MASS     +
++++++++++++++++++++++++++
C     COMPUTE,INVERT AND PRINT MASS MATRICES
*     LABEL
*     FORTRAN
*     LIST
CMASS
      SUBROUTINE MASS
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),ZO(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),O(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,ZO,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      DO 11=1,NMODE
      DO1 J=1,NMODE
      XMC1(I,J)=0.0
      XMC3(I,J)=0.0
    1 XMC4(I,J)=0.0
      DO 2 I=1,NMODE
    2 XMC1(I,I)=XM(I)
      DO3I=1,2
      XMC3(I,I)=-((-1.0)**I)*XM(I)
    3 XMC4(I,I)=-XMC3(I,I)
      DO4 I=3,NMODE
      XMC3(I,I)=XM(I)
      XMC3(2,I)=XM(2)*FE(I,2)
      XMC3(I,2)=XMC3(2,I)
      XMC4(I,I)=XM(I)
      XMC4(I,I)=XM(I)*FE(I,1)
    4 XMC4(I,I)=XMC4(I,I)
      DO5 I=1,NMODE
      DO 5 J=1,NMODE
    5 XMC2(I,J)=XMC3(I,J)+XMC4(I,J)-XMC1(I,J)
      DO 30 I=1,NMODE
      DO 30 J=1,NMODE
      XMC1I(I,J)=XMC1(I,J)
      XMC2I(I,J)=XMC2(I,J)
      XMC3I(I,J)=XMC3(I,J)
   30 XMC4I(I,J)=XMC4(I,J)
      CALL SYMINV(XMC1I,NMODE)
      CALL SYMINV(XMC2I,NMODE)
      CALL SYMINV(XMC3I,NMODE)
      CALL SYMINV(XMC4I,NMODE)
      IF(LP-1)21,20,21
   20 PRINT 6
    6 FORMAT(8H    XMC1)
      CALL PRINTM(XMC1,NMODE,NMODE,12)
      PRINT 7
    7 FORMAT(8H    XMC2)
      CALL PRINTM(XMC2,NMODE,NMODE,12)
      PRINT 8
    8 FORMAT(8H    XMC3)
      CALL PRINTM(XMC3,NMODE,NMODE,12)
      PRINT 9
    9 FORMAT(8H    XMC4)
      CALL PRINTM(XMC4,NMODE,NMODE,12)
      PRINT 50
   50 FORMAT(9H    XMC1I)
      CALL PRINTM(XMC1I,NMODE,NMODE,12)
      PRINT 51
   51 FORMAT(9H    XMC2I)
      CALL PRINTM(XMC2I,NMODE,NMODE,12)
      PRINT 52
   52 FORMAT(9H    XMC3I)
      CALL PRINTM(XMC3I,NMODE,NMODE,12)
      PRINT 53
   53 FORMAT(9H    XMC4I)
      CALL PRINTM(XMC4I,NMODE,NMODE,12)
   21 RETURN
      END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE CK2      +
++++++++++++++++++++++++++
C     COMPUTE DAMPING AND STIFFNESS MATRICES FOR THE CASE WHEN BOTH
C     LANDING GEARS ARE LOCKED
*     LABEL
*     FORTRAN
*     LIST
CCK2
      SUBROUTINE CK2
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(112),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      I=1
      DO 10 K=1,NMODE
      DO 10 K1=1,NMODE
   10 XCC2(K,K1)=0.0
      DO 11 K=1,NMODE
   11 XCC2(K,K)=XC(K)
      DO 20 K=1,2
      DO 20 K1=K,NMODE
   20 XKC2(K,K1)=0.0
      DO 22 K=3,NMODE
      DO 21 K1=K,NMODE
      XKC2(K,K1)=0.0
      DO 21 K3=1,2
   21 XKC2(K,K1)=XXKT(K3)*FE(K,K3)*FE(K1,K3)+XKC2(K,K1)
   22 XKC2(K,K)=XKC2(K,K)+XM(K)*OMEGA(K)**2
      DO23 K=1,NM
      K3=K+1
      DO 23 K4=K3,NMODE
   23 XKC2(K4,K)=XKC2(K,K4)
      IF(LP-1)31,30,31
   30 PRINT6
    6 FORMAT(8H     XCC2)
      CALL PRINTM(XCC2,NMODE,NMODE,12)
      PRINT 7
    7 FORMAT(8H     XKC2)
      CALL PRINTM(XKC2,NMODE,NMODE,12)
   31 DO 150 K9=1,NMODE
      DO 150 K9=1,NMODE
  150 XFC2(K8,K9)=XMC2(K8,K9)+(DT(I)/2.0)*XCC2(K8,K9)+((DT(I)**2)/6.0)*
     1XKC2(K8,K9)
      IF(LP-1)161,160,161
  160 PRINT 162
  162 FORMAT(8H     XFC2)
      CALL PRINTM(XFC2,NMODE,NMODE,12)
  161 CALL SYMINV(XFC2,NMODE)
      IF DIVIDE CHECK 163,164
  163 CALL EXIT
  164 IF(LP-1)32,170,32
  170 PRINT 172
  172 FORMAT(9H     XFC2I)
      CALL PRINTM(XFC2,NMODE,NMODE,12)
   32 RETURN
      END
```

```
++++++++++++++++++++++++++
+     SUBROUTINE CK34     +
++++++++++++++++++++++++++
C     COMPUTE THE DAMPING AND STIFFNESS MATRICES FOR THE CASES WHEN
C     EITHER BOTH GEARS ARE UNLOCKED OR ONE OF THE GEARS ARE UNLOCKED
*     LABEL
*     FORTRAN
*     LIST
CCK34
      SUBROUTINE CK34
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(112),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      DO4 K=KK,KKK
      XDS(K)=0.0
      XXDS(K)=DS(K,1)
      NNFS=NFS(K)
      IF(SIN(K)-SMAX(K))5,5,6
    6 PRINT 20,K,J,K
   20 FORMAT(2HS(I5,1H,I5,1H)14H EXCEEDS SMAX(I5,1H))
      CALL EXIT
    5 DO10 K1=2,NNFS
      IF(SIN(K)-XXDS(K))2,2,3
    2 XKS1(K)=(XFS(K,K1)-XFS(K,K1-1))/DS(K,K1-1)
      XKS2(K)=XFS(K,K1-1)-XKS1(K)*XDS(K)
      GOTO4
    3 XDS(K)=XDS(K)+DS(K,K1-1)
      XXDS(K)=XXDS(K)+DS(K,K1)
   10 CONTINUE
    4 CONTINUE
      DO24 K=KK,KKK
      XGS(K)=0.0
      XXGS(K)=DG(K,1)
      NNGS=NGS(K)
      DO25 K1=2,NNGS
      IF(SIN(K)-XXGS(K))26,26,27
   26 GS(K)=((XG(K,K1)-XG(K,K1-1))/DG(K,K1-1))*(SIN(K)-XGS(K))
     1+XG(K,K1-1)
      GOTO24
   27 XGS(K)=XGS(K)+DG(K,K1-1)
      XXGS(K)=XXGS(K)+DG(K,K1)
   25 CONTINUF
   24 CONTINUE
      DO28 K=KK,KKK
      GH=GS(K)*S1IN(K)
   28 G1(K)=ABSF(GH)
      XKC(1,2)=0.0
      XCC(1,2)=0.0
      DO29K=1,2
      XKC(K,K)=XKS1(K)+XXKT(K)
   29 XCC(K,K)=G1(K)
      DO12 K=1,2
      DO12 K1=3,NMODE
      XKC(K,K1)=-XKS1(K)*FE(K1,K)
   12 XCC(K,K1)=-G1(K)*FE(K1,K)
      IF(KK-KKK)31,32,31
   32 IF(KK-1)41,41,42
   42 KQ=1
      GOTO40
   41 KQ=2
   40 DO13K=KQ,KQ
      DO13 K1=1,NMODE
      XKC(K,K1)=0.0
   13 XCC(K,K1)=0.0
   31 CONTINUE
      DO35 K1=3,NMODE
      DO 34 K2=K1,NMODE
      XKC(K1,K2)=0.0
      DO34 K3=1,2
   34 XKC(K1,K2)=XKS1(K3)*FE(K2,K3)*FE(K1,K3)+XKC(K1,K2)
   35 XKC(K1,K1)=XKC(K1,K1)+XM(K1)*OMEGA(K1)**2
      DO 45 K1=3,NMODE
      DO 44 K2=K1,NMODE
      XCC(K1,K2)=0.0
      DO 44 K3=KK,KKK
   44 XCC(K1,K2)=G1(K3)*FE(K1,K3)*FE(K2,K3)+XCC(K1,K2)
   45 XCC(K1,K1)=XCC(K1,K1)+XC(K1)
      DO 36 K=1,NM
      K3=K+1
      DO 36 K4=K3,NMODE
      XKC(K4,K)=XKC(K,K4)
   36 XCC(K4,K)=XCC(K,K4)
      RETURN
      END
```

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++++++++++++++++++++++++++
+     SUBROUTINE C1       +
++++++++++++++++++++++++++
C     COMPUTE RESPONSE OF AIRPLANE FOR THE CASE WHEN BOTH LANDING GEARS
C     ARE UNLOCKED
*     LABEL
*     FORTRAN
*     LIST
CC1
      SUBROUTINE C1
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(112),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      LPP=2
      KK=1
      KKK=2
      DO 100 K=1,2
      XXKT(K)=XKT(K)
      IF(FSTIN(K))101,101,100
  101 XXKT(K)=0.0
  100 CONTINUE
      CALL CK34
      DO51 K=1,2
   51 SC(K)=W(K)+F(K,J1)+XKS1(K)*XST(K)+XKS2(K)-XXKT(K)*(ZST(K)+DELTA(
     1K,J1))
      DO 52 K=3,NMODE
   52 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)-FE(K,2)*(F(2,J1)+XKS1(2)
     1*XST(2)+XKS2(2))-FE(K,1)*(F(1,J1)+XKS1(1)*XST(1)+XKS2(1))
     2+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO54 K=1,NMODE
      XCA(K)=0.0
      XKB(K)=0.0
      DO54 K1=1,NMODE
      XCA(K)=XCC(K,K1)*XA(K1)+XCA(K)
   54 XKB(K)=XKC(K,K1)*XB(K1)+XKB(K)
```

```
      DO55 K=1,NMODE
      PC1(K)=SC(K)-XCA(K)-XKB(K)
   55 PC(K)=PC1(K)
      DO 60 K=1,NMODE
      DO 60 K1=1,NMODE
   60 XFC(K,K1)=XMC1(K,K1)+(DT(I)/2.0)*XCC(K,K1)+((DT(I)**2)/6.0)
     1*XKC(K,K1)
      CALL SOLEQU(XFC,NMODE,PC1,1)
      IF(XFC)80,80,81
   81 PRINT 82
   82 FORMAT(2HXFC GREATER THAN ZERO)
      CALL EXIT
   80 DO56 K=1,NMODF
      Z2(K,J1)=PC1(K)
      Z3(K,J1)=Z2(K,J1)
      Z(K,J1)=XB(K)+((DT(I)**2)/2.0)*Z2(K,J1)
   56 Z1(K,J1)=XA(K)+(DT(I)/2.0)*Z2(K,J1)
      DO58 K=1,2
      U(K,J1)=0.0
      U1(K,J1)=0.0
      U2(K,J1)=0.0
      DO57 K1=3,NMODE
      U(K,J1)=U(K,J1)+Z(K1,J1)*FE(K1,K)
      U1(K,J1)=U1(K,J1)+Z1(K1,J1)*FE(K1,K)
      U2(K,J1)=U2(K,J1)+Z2(K1,J1)*FE(K1,K)
   57 U3(K,J1)=U2(K,J1)
      Z0(K,J1)=U(K,J1)-Z(K,J1)
      S(K,J1)=Z0(K,J1)+XST(K)
      S1(K,J1)=U1(K,J1)-Z1(K,J1)
      S2(K,J1)=U2(K,J1)-Z2(K,J1)
      IF(ZST(K)+Z(K,J1)+DELTA(K,J1))400,400,401
  401 XXKT(K)=XKT(K)
  400 FST(K,J1)=XXKT(K)*(ZST(K)+Z(K,J1)+DELTA(K,J1))
      IF(S(K,J1))200,200,201
  200 FS(K,J1)=XKS2(K)
      GOTO 202
  201 FS(K,J1)=XKS1(K)*S(K,J1)+XKS2(K)
  202 GG=G1(K)
      FD(K,J1)=ABSF(GG)*S1(K,J1)
   58 Q(K,J1)=F(K,J1)+FS(K,J1)+FD(K,J1)
      XL(1,J1)=(XL11+XL12*(THETA(1,J1)+Z(4,J1)))*V(J1)**2
      XL(2,J1)=(XL21+XL22*(THETA(2,J1)+Z(4,J1)))*V(J1)**2
      IF(LP-1)21,20,21
   20 PRINT 70,M1
   70 FORMAT(9H       M1=,I5)
      PRINT 71
   71 FORMAT(6X6HSUB C1)
      CALL PR1
   21 RETURN
      END


++++++++++++++++++++++++
+     SUBROUTINE C2      +
++++++++++++++++++++++++
C     COMPUTE RESPONSE OF AIRPLANE FOR THE CASE WHEN BOTH LANDING GEARS
C     ARE LOCKED
*     LABEL
*     FORTRAN
*     LIST
CC2
      SUBROUTINE C2
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,2),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      DO 100 K=1,2
      XXKT(K)=XKT(K)
      IF(FSTIN(K))101,101,100
  101 XXKT(K)=0.0
  100 CONTINUE
      CALL CK2
      LPP=1
      DO51 K=1,2
      Z0(K,J1)=ZOIN(K)
   51 SC(K)=0.0
      DO 52 K=3,NMODE
   52 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,1)*(XXKT(1)*(ZST(1)+DELTA(1,J1)-Z0(1,J1))-W(1))
     2-FE(K,2)*(XXKT(2)*(ZST(2)+DELTA(2,J1)-Z0(2,J1))-W(2))
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO54 K=1,NMODE
      XCA(K)=0.0
      XKB(K)=0.0
      DO54 K1=1,NMODE
      XCA(K)=XCC2(K,K1)*XA(K1)+XCA(K)
   54 XKB(K)=XKC2(K,K1)*XB(K1)+XKB(K)
      DO55 K=1,NMODE
      PC1(K)=SC(K)-XCA(K)-XKB(K)
   55 PC(K)=PC1(K)
      DO60K=1,NMODE
      Z2(K,J1)=0.0
      DO 60 K1=1,NMODE
   60 Z2(K,J1)=XFC2(K,K1)*PC1(K1)+Z2(K,J1)
      DO56K=1,NMODE
   56 Z3(K,J1)=Z2(K,J1)
      DO57 K=3,NMODE
      Z(K,J1)=XB(K)+((DT(I)**2)/2.0)*Z2(K,J1)
   57 Z1(K,J1)=XA(K)+(DT(I)/2.0)*Z2(K,J1)
      DO59 K=1,2
      U(K,J1)=0.0
      U1(K,J1)=0.0
      DO58 K1=3,NMODE
      U(K,J1)=U(K,J1)+Z(K1,J1)*FE(K1,K)
   58 U1(K,J1)=U1(K,J1)+Z1(K1,J1)*FE(K1,K)
      U2(K,J1)=Z2(K,J1)
      U3(K,J1)=U2(K,J1)
      Z(K,J1)=U(K,J1)-Z0(K,J1)
      Z1(K,J1)=U1(K,J1)
      S(K,J1)=Z0(K,J1)+XST(K)
      S1(K,J1)=0.0
      S2(K,J1)=0.0
      IF(ZST(K)+Z(K,J1)+DELTA(K,J1))400,400,401
  401 XXKT(K)=XKT(K)
  400 FST(K,J1)=XXKT(K)*(ZST(K)+Z(K,J1)+DELTA(K,J1))
      FS(K,J1)=FSIN(K)
      FD(K,J1)=0.0
      F(K,J1)=XM(K)*Z2(K,J1)-W(K)-FS(K,J1)+FST(K,J1)
   59 Q(K,J1)=FS(K,J1)+F(K,J1)
      XL(1,J1)=(XL11+XL12*(THETA(1,J1)+Z(4,J1)))*V(J1)**2
      XL(2,J1)=(XL21+XL22*(THETA(2,J1)+Z(4,J1)))*V(J1)**2
      IF(LP-1)21,20,21
   20 PRINT 70,M1
   70 FORMAT(9H       M1=,I5)
      PRINT 71
   71 FORMAT(6X6HSUB C2)
      CALL PR1
   21 RETURN
      END


++++++++++++++++++++++++
+     SUBROUTINE C34     +
++++++++++++++++++++++++
C     COMPUTE RESPONSE OF AIRPLANE FOR THE CASE WHEN EITHER ONE OF THE
C     LANDING GEARS IS LOCKED
*     LABEL
*     FORTRAN
*     LIST
CC34
      SUBROUTINE C34
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,2),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      DO 200 K=1,2
      XXKT(K)=XKT(K)
      IF(FSTIN(K))201,201,200
  201 XXKT(K)=0.0
  200 CONTINUE
      LPP=2
      KZ=KZ
      KZZ=KZZ
      KK=KZ
      KKK=KZ
      XKS1(KZZ)=XXKT(KZZ)
      CALL CK34
      Z0(KZZ,J1)=ZOIN(KZZ)
      SC(KZ)=W(KZ)+F(KZ,J1)+XKS1(KZ)*XS1(KZ)+XKS2(KZ)
     1-XXKT(KZ)*(ZST(KZ)+DELTA(KZ,J1))
      SC(KZZ)=0.0
      DO40 K=3,NMODE
   40 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,KZ)*(F(KZ,J1)+XKS1(KZ)*XST(KZ)+XKS2(KZ))
     2-FE(K,KZZ)*(XXKT(KZZ)*(ZST(KZZ)+DELTA(KZZ,J1)-Z0(KZZ,J1))-W(KZZ))
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO54 K=1,NMODE
      XCA(K)=0.0
      XKB(K)=0.0
      DO54 K1=1,NMODE
      XCA(K)=XCC(K,K1)*XA(K1)+XCA(K)
   54 XKB(K)=XKC(K,K1)*XB(K1)+XKB(K)
      DO55 K=1,NMODE
      PC1(K)=SC(K)-XCA(K)-XKB(K)
   55 PC(K)=PC1(K)
      IF (KPP-1) 101,100,101
  100 DO 105 K=1,NMODE
      DO 105 K1=1,NMODE
  105 XMC(K,K1)=XMC3(K,K1)
      GO TO 107
  101 DO 106 K=1,NMODE
      DO 106 K1=1,NMODE
  106 XMC(K,K1)=XMC4(K,K1)
  107 DO 60 K=1,NMODE
      DO 60 K1=1,NMODE
   60 XFC(K,K1)=XMC(K,K1)+(DT(I)/2.0)*XCC(K,K1)+((DT(I)**2)/6.0)*XKC(K,K
     1 1)
      CALL SOLEQU(XFC,NMODE,PC1,1)
      IF(XFC)81,81,82
   82 PRINT 83
   83 FORMAT(21HXFC GREATER THAN ZERO)
      CALL EXIT
   81 DO 56 K=1,NMODE
      Z2(K,J1)=PC1(K)
      Z3(K,J1)=Z2(K,J1)
      Z(K,J1)=XB(K)+((DT(I)**2)/2.0)*Z2(K,J1)
   56 Z1(K,J1)=XA(K)+(DT(I)/2.0)*Z2(K,J1)
      DO58 K=1,2
      U(K,J1)=0.0
      U1(K,J1)=0.0
```

```
      U2(K,J1)=0.0
      DO58 K1=3,NMODE
      U(K,J1)=U(K,J1)+Z(K1,J1)*FE(K1,K)
      U1(K,J1)=U1(K,J1)+Z1(K1,J1)*FE(K1,K)
   58 U2(K,J1)=U2(K,J1)+Z2(K1,J1)*FE(K1,K)
      Z(KZZ,J1)=U(KZZ,J1)-Z0(KZZ,J1)
      Z1(KZZ,J1)=U1(KZZ,J1)
      Z2(KZ,J1)=U(KZ,J1)-Z(KZ,J1)
      DO59 K=1,2
      U3(K,J1)=U2(K,J1)
      S(K,J1)=Z0(K,J1)+XST(K)
      S1(K,J1)=U1(K,J1)-Z1(K,J1)
      S2(K,J1)=U2(K,J1)-Z2(K,J1)
      IF(ZST(K)+Z(K,J1)+DELTA(K,J1))59,59,401
  401 XXKT(K)=XKT(K)
   59 FST(K,J1)=XKKT(K)*(ZST(K)+Z(K,J1)+DELTA(K,J1))
      IF(S(KZ,J1))300,300,301
  300 FS(KZ,J1)=XKS2(KZ)
      GOTO 302
  301 FS(KZ,J1)=XKS1(KZ)*S(KZ,J1)+XKS2(KZ)
  302 FS(KZZ,J1)=FSIN(KZZ)
      GG=G1(KZ)
      FD(KZ,J1)=ABSF(GG)*S1(KZ,J1)
      FD(KZZ,J1)=0.0
      F(KZZ,J1)=XM(KZZ)*Z2(KZZ,J1)-W(KZZ)-FS(KZZ,J1)+FST(KZZ,J1)
      Q(KZ,J1)=F(KZ,J1)+FS(KZ,J1)+FD(KZ,J1)
      Q(KZZ,J1)=F(KZZ,J1)+FS(KZZ,J1)
      XL(1,J1)=(XL11+XL12*(THETA(1,J1)+Z(4,J1)))*V(J1)**2
      XL(2,J1)=(XL21+XL22*(THETA(2,J1)+Z(4,J1)))*V(J1)**2
      IF(LP-1)21,20,21
   20 PRINT 70,M1
   70 FORMAT(9H      M1=,I5)
      PRINT 71
   71 FORMAT(6X7HSUB C34)
      PRINT 80
   80 FORMAT(9H      KPP=,I5)
      CALL PR1
   21 RETURN
      END


++++++++++++++++++++++++
+     SUBROUTINE PR1     +
++++++++++++++++++++++++
C     PRINT THE DAMPING AND STIFFNESS MATRICES AND THE RESPONSE
C     OBTAINED FROM EITHER ONE OF THE SUBROUTINES C1 OR C2 OR C34
*     LABEL
*     FORTRAN
*     LIST
CPR1
      SUBROUTINE PR1
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S1(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION Z1N(12),Z1IN(12),Z2N(12),Z2IN(12),Z3N(12),U1N(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),Z0IN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,U1,U1,U2,U3,NP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,U1N,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,Z0IN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT
      IF(LPP-1)80,81,80
   80 PRINT 72
   72 FORMAT(8H      XCC)
      CALL PRINTM(XCC,NMODE,NMODE,12)
      PRINT 73
   73 FORMAT(8H      XKC)
      CALL PRINTM(XKC,NMODE,NMODE,12)
   81 PRINT 75
   75 FORMAT(6X3HSC ,11X3HXCA,11X3HXKB,11X3HPC ,11X3HZ  ,11X3HZ1 ,
     11X3HZ2 )
      DO 76 K=1,NMODE
   76 PRINT 77,SC(K),XCA(K),XKB(K),PC(K),Z(K,J1),Z1(K,J1),Z2(K,J1)
   77 FORMAT(8E14.6)
      PRINT 78
   78 FORMAT(6X3HU  ,11X3HU1 ,11X3HU2 ,11X3HZO ,11X3HFST,11X3HFS ,
     11X3HFD ,11X3HF
      DO79 K=1,2
   79 PRINT 77,U(K,J1),U1(K,J1),U2(K,J1),Z0(K,J1),FST(K,J1),FS(K,J1),
     1FD(K,J1),F(K,J1)
      RETURN
      END


++++++++++++++++++++++++
+     SUBROUTINE CA1     +
++++++++++++++++++++++++
C     RECOMPUTE RESPONSE IF STROKE VELOCITY CHANGES SIGN
*     LABEL
*     FORTRAN
*     LIST
CCA1
      SUBROUTINE CA1
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION Z1N(12),Z1IN(12),Z2IN(12),Z3IN(12),U1N(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),Z0IN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,NP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,U1N,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,Z0IN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      KV=KV
      KVV=KVV
      IF (KD-1) 30,30,31
   30 DO 32 K=1,NMODE
      DO 32 K1=1,NMODE
   32 XMC(K,K1)=XMC3I(K,K1)
      GO TO 40
   31 DO 33 K=1,NMODE
      DO 33 K1=1,NMODE
   33 XMC(K,K1)=XMC4I(K,K1)
   40 SC(KV)=0.0
      SC(KVV)=W(KVV)+FS(KVV,J1)+FD(KVV,J1)+F(KVV,J1)-FST(KVV,J1)
      DO 1 K=3,NMODE
    1 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,1)*(FST(1,J1)-W(1))-FE(K,2)*(FST(2,J1)-W(2))
     2-XC(K)*Z1(K,J1)-XM(K)*OMEGA(K)**2*Z(K,J1)
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO4K=1,NMODE
      Z3(K,J1)=0.0
      DO4K1=1,NMODE
    4 Z3(K,J1)=XMC(K,K1)*SC(K1)+Z3(K,J1)
      DO5K=1,2
      F(K,J1)=XM(K)*Z3(K,J1)-W(K)-FS(K,J1)+FST(K,J1)
    5 Q(K,J1)=F(K,J1)+FS(K,J1)
      DO6K=1,2
      U3(K,J1)=0.0
      DO6K1=3,NMODE
    6 U3(K,J1)=U3(K,J1)+Z3(K1,J1)*FE(K1,K)
      IF(LP-1)21,20,21
   20 PRINT 10,M1
   10 FORMAT(9H      M1=,I5)
      PRINT11
   11 FORMAT(6X7HSUB CA1)
      PRINT 16
   16 FORMAT(6X2HSC,12X2HZ3)
      DO17 K=1,NMODE
   17 PRINT 18,SC(K),Z3(K,J1)
   18 FORMAT(3E14.6)
      PRINT 12
   12 FORMAT(6X2HU3,11X2H F)
      DO 13 K=1,2
   13 PRINT18,U3(K,J1),F(K,J1)
   21 RETURN
      END


++++++++++++++++++++++++
+     SUBROUTINE CA23    +
++++++++++++++++++++++++
C     RECOMPUTE RESPONSE IF STROKE VELOCITY CHANGES SIGN
*     LABEL
*     FORTRAN
*     LIST
CCA23
      SUBROUTINE CA23
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION Z1N(12),Z1IN(12),Z2IN(12),Z3IN(12),U1N(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),Z0IN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,NP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,U1N,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,Z0IN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      KV=KV
      KVV=KVV
      IF (KD-1) 30,30,31
   30 DO 32 K=1,NMODE
      DO 32 K1=1,NMODE
   32 XMC(K,K1)=XMC3I(K,K1)
      GO TO 40
   31 DO 33 K=1,NMODE
      DO 33 K1=1,NMODE
   33 XMC(K,K1)=XMC4I(K,K1)
   40 SC(KV)=0.0
      SC(KVV)=W(KVV)+FS(KVV,J1)+FD(KVV,J1)+F(KVV,J1)-FST(KVV,J1)
      DO 1 K=3,NMODE
    1 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,KV)*(FST(KV,J1)-W(KV))-FE(K,KVV)*(F(KVV,J1)+FS(KVV,J1)+
     2FD(KVV,J1))-XC(K)*Z1(K,J1)-XM(K)*OMEGA(K)**2*Z(K,J1)
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO4K=1,NMODE
      Z3(K,J1)=0.0
      DO4K1=1,NMODE
    4 Z3(K,J1)=XMC(K,K1)*SC(K1)+Z3(K,J1)
      F(KV,J1)=XM(KV)*Z3(KV,J1)-W(KV)-FS(KV,J1)+FST(KV,J1)
      Q(KV,J1)=F(KV,J1)+FS(KV,J1)
      DO6K=1,2
      U3(K,J1)=0.0
      DO6K1=3,NMODE
    6 U3(K,J1)=U3(K,J1)+Z3(K1,J1)*FE(K1,K)
      IF(LP-1)21,20,21
   20 PRINT 10,M1
   10 FORMAT(9H      M1=,I5)
      PRINT11
   11 FORMAT(6X8HSUB CA23)
      PRINT 25,KD
   25 FORMAT(9H      KD=,I5)
      PRINT 16
   16 FORMAT(6X2HSC,12X2HZ3)
      DO17 K=1,NMODE
   17 PRINT 18,SC(K),Z3(K,J1)
   18 FORMAT(3E14.6)
      PRINT 12
   12 FORMAT(6X2HU3,11X2H F)
```

```
      DO 13 K=1,2
   13 PRINT18,U3(K,J1),F(K,J1)
   21 RETURN
      END

++++++++++++++++++++++++
+     SUBROUTINE B1     +
++++++++++++++++++++++++
C     TEST WHETHER STROKE VELOCITY HAS CHANGED SIGN
*     LABEL
*     FORTRAN
*     LIST
CB1
      SUBROUTINE B1
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
     7PC1(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      IF(LP-1)208,209,208
  209 PRINT 201
  201 FORMAT(6X6HSUB B1)
  208 IF(U4(1)-Z4(1))20,10,10
   10 IF(U4(2)-Z4(2))40,200,200
  200 IF(LP-1)207,206,207
  206 PRINT 203,M1
  203 FORMAT(9H       M1=,I5)
      PRINT 202
  202 FORMAT(6X4HEXIT)
  207 GOTO100
   40 Z1(2,J1)=U1(2,J1)
      FD(2,J1)=0.0
      IF(LP-1)404,405,404
  405 PRINT 204
  204 FORMAT(6X3HZ12,10X3HU12)
      PRINT 205,Z1(2,J1),U1(2,J1)
  205 FORMAT(3E14.6)
  404 KV=2
      KVV=1
      KD=1
```

```
++++++++++++++++++++++++
+     SUBROUTINE B23    +
++++++++++++++++++++++++
C     TEST WHETHER STROKE VELOCITY HAS CHANGED SIGN
*     LABEL
*     FORTRAN
*     LIST
CB23
      SUBROUTINE B23
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC1(12),
     7PC(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),ZOIN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,J,J1,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,ZOIN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      KX1=KX1
      KX2=KX2
      IF(LP-1)208,209,208
  209 PRINT 201
  201 FORMAT(6X7HSUB B23)
      PRINT 220,KDD
  220 FORMAT(9H       KDD=,I5)
  208 IF(U4(KX1)-Z4(KX1))20,10,10
   10 IF(KX1-1)400,400,401
  400 KX=2
      GOTO111
  401 KX=1
  111 IF(F(KX,J1)-F1(KX))120,110,110
  110 F(KX,J1)=F1(KX)
    8 DO1K=1,2
      Q(K,J1)=FS(K,J1)+F(K,J1)+FD(K,J1)
    1 Z3(K,J1)=(W(K)+Q(K,J1)-FST(K,J1))/XM(K)
      DO3K=3,NMODE
    3 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,1)*Q(1,J1)-FE(K,2)*Q(2,J1)
     2-XC(K)*Z1(K,J1)-XM(K)*OMEGA(K)**2*Z(K,J1)
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO5K=3,NMODE
    5 Z3(K,J1)=SC(K)/XM(K)
      DO6K=1,2
      U3(K,J1)=0.0
      DO6 K1=3,NMODE
    6 U3(K,J1)=U3(K,J1)+Z3(K1,J1)*FE(K1,K)
```

```
      CALL CA23
      KX=2
  111 IF(F(KX,J1)-F1(KX))120,110,110
  110 F(KX,J1)=F1(KX)
    8 DO1K=1,2
      Q(K,J1)=FS(K,J1)+F(K,J1)+FD(K,J1)
    1 Z3(K,J1)=(W(K)+Q(K,J1)-FST(K,J1))/XM(K)
      DO3K=3,NMODE
    3 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,1)*Q(1,J1)-FE(K,2)*Q(2,J1)
     2+FE(K,1)*FSST1+FE(K,2)*FSST2
     3-XC(K)*Z1(K,J1)-XM(K)*OMEGA(K)**2*Z(K,J1)
      DO 5 K=3,NMODE
    5 Z3(K,J1)=SC(K)/XM(K)
      DO6K=1,2
      U3(K,J1)=0.0
      DO6 K1=3,NMODE
    6 U3(K,J1)=U3(K,J1)+Z3(K1,J1)*FE(K1,K)
      IF(LP-1)31,30,31
   30 PRINT 32,M1
   32 FORMAT(9H       M1=,I5)
      PRINT 33
   33 FORMAT(6X6HSUB XB)
      PRINT 34
   34 FORMAT(6X2HZ3)
      DO 35 K=1,NMODE
   35 PRINT 205,Z3(K,J1)
      PRINT 36
   36 FORMAT(6X2HF ,11X2HU3)
      DO37K=1,2
   37 PRINT 205,F(K,J1),U3(K,J1)
  205 FORMAT(3E14.6)
   31 GOTO100
  120 IF(F(KX,J1)+F1(KX))130,100,100
  130 F(KX,J1)=-F1(KX)
      GOTO8
   20 Z1(1,J1)=U1(1,J1)
      FD(1,J1)=0.0
      IF(LP-1)406,407,406
  407 PRINT 304
  304 FORMAT(6X3HZ11,10X3HU11)
      PRINT 205,Z1(1,J1),U1(1,J1)
  406 IF(U4(2)-Z4(2))60,50,50
   50 KV=1
      KVV=2
      KD=2
      CALL CA23
      KX=1
      GOTO111
   60 Z1(2,J1)=U1(2,J1)
      FD(2,J1)=0.0
      IF(LP-1)408,409,408
  409 PRINT 204
      PRINT 205,Z1(2,J1),U1(2,J1)
  408 CALL CA1
      CALL XA3
  100 RETURN
      END
```

```
      IF(LP-1)31,30,31
   30 PRINT 32,M1
   32 FORMAT(9H       M1=,I5)
      PRINT 33
   33 FORMAT(6X6HSUB XB)
      PRINT 34
   34 FORMAT(6X2HZ3)
      DO 35 K=1,NMODE
   35 PRINT 205,Z3(K,J1)
      PRINT 36
   36 FORMAT(6X2HF ,11X2HU3)
      DO37K=1,2
   37 PRINT 205,F(K,J1),U3(K,J1)
  205 FORMAT(3E14.6)
   31 GOTO100
  120 IF(F(KX,J1)+F1(KX))130,100,100
  130 F(KX,J1)=-F1(KX)
      GOTO8
   20 Z1(KX1,J1)=U1(KX1,J1)
      FD(KX1,J1)=0.0
      IF(LP-1)22,21,22
   21 IF(KX1-1)23,23,24
   23 PRINT 304
  304 FORMAT(6X3HZ11,10X3HU11)
      PRINT 205,Z1(1,J1),U1(1,J1)
      GOTO 22
   24 PRINT 305
  305 FORMAT(6X3HZ12,10X3HU12)
      PRINT 205,Z1(2,J1),U1(2,J1)
   22 IF(F(KX2,J1)-F1(KX2))40,70,70
   70 F(KX2,J1)=F1(KX2)
   74 IF(KX2-1)71,71,72
   71 KV=2
      KVV=1
      KD=1
      CALL CA23
      KX=2
      GOTO111
   72 KV=1
      KVV=2
      KD=2
      CALL CA23
   73 KX=1
      GOTO111
   40 IF(F(KX2,J1)+F1(KX2))50,60,60
   50 F(KX2,J1)=-F1(KX2)
      GOTO74
   60 CALL CA1
      CALL XA3
  100 RETURN
      END

++++++++++++++++++++++++
+     SUBROUTINE XA3    +
++++++++++++++++++++++++
C     TEST WHETHER COULOMB FRICTION FORCE HAS EXCEEDED ITS LIMITING VALUE
*     LABEL
*     FORTRAN
*     LIST
```

```
CXA3
      SUBROUTINE XA3
      DIMENSION Z(12,200),Z1(12,200),Z2(12,200),Z3(12,200),Z4(2),
     1U(2,200),U1(2,200),U2(2,200),U3(2,200),U4(2),Z0(2,200),S(2,200),
     2S1(2,200),S2(2,200),F(2,200),FS(2,200),FD(2,200),F1(2),Q(2,200),
     3FST(2,200),XL(2,200),THETA(2,200),DELTA(2,200),V(200),XST(2),W(3),
     4SMAX(2),XM(12),XC(12),OMEGA(12),FE(12,10),XKT(2),NFS(2),XKS1(2),
     5XKS2(2),XFS(2,20),DS(2,20),XDS(2),XXDS(2),NGS(2),XG(2,50),XGS(2),
     6DG(2,50),XXGS(2),XA(12),XB(12),XCA(12),XKB(12),SC(12),PC(12),
     7PC1(12),XFC(12,12),XFC2(12,12),XMC1(12,12),XMC2(12,12),XMC3(12,12),
     8XMC4(12,12),XCC(12,12),XCC2(12,12),XKC(12,12),XKC2(12,12),DT(50),
     9N1(50),G1(2),GS(2),UST(2),ZST(2),XMC(12,12)
      DIMENSION ZIN(12),Z1IN(12),Z2IN(12),Z3IN(12),UIN(2),U1IN(2),
     1U2IN(2),U3IN(2),SIN(2),S1IN(2),S2IN(2),FIN(2),Z0IN(2),FSIN(2),
     2FSTIN(2),FDIN(2),XMC1I(12,12),XMC2I(12,12),XMC3I(12,12),
     3XMC4I(12,12),XXKT(2)
      COMMON Z,Z1,Z2,Z3,Z4,U,U1,U2,U3,U4,Z0,S,S1,S2,Q,F,FS,FD,F1,XL,KJ,
     1FST,THETA,DELTA,V,XST,SMAX,XM,W,XC,OMEGA,FE,XKT,NFS,XKS1,XKS2,XFS,
     2DS,XDS,XXDS,NGS,XG,DG,XGS,XXGS,XA,XB,XCA,XKB,SC,PC,PC1,XFC,XMC1,
     3XMC2,XMC3,XMC4,XCC,XCC2,XKC,XKC2,DT,N1,G1,GS,MP,LP,LPP,KP,KPP,JP,
     4MP1,IT1,KP1,NMODE,NPT,NM,XLAMDA,XL11,XL12,XL21,XL22,NFS1,NFS2,
     5NFS11,NFS21,NGS1,NGS2,NGS11,NGS21,NT,KK,KKK,M,M1,KZ,KZZ,JJ,JI,KV,
     6KVV,KX,KX1,KX2,IT,IL,I,NX,JX,JXX,G,XFC2,KD,KDD,KW,KWW,ZST,UST,XMC,
     7ZIN,Z1IN,Z2IN,Z3IN,UIN,U1IN,U2IN,U3IN,SIN,S1IN,S2IN,FIN,Z0IN,
     8FSIN,FSTIN,FDIN,XMC1I,XMC2I,XMC3I,XMC4I,XXKT,FSST1,FSST2
      PRINT 300
  300 FORMAT(6X7HSUB XA3)
      IF(F(1,J1)-F1(1))60,10,10
   10 IF(F(2,J1)-F1(2))70,20,20
   20 DO21 K=1,2
   21 F(K,J1)=F1(K)
    8 DO1K=1,2
      Q(K,J1)=FS(K,J1)+F(K,J1)+FD(K,J1)
    1 Z3(K,J1)=(W(K)+Q(K,J1)-FST(K,J1))/XM(K)
      DO3K=3,NMODE
    3 SC(K)=-XL(1,J1)*FE(K,3)-XL(2,J1)*FE(K,4)
     1-FE(K,1)*Q(1,J1)-FE(K,2)*Q(2,J1)
     2-XC(K)*Z1(K,J1)-XM(K)*OMEGA(K)**2*Z(K,J1)
     3+FE(K,1)*FSST1+FE(K,2)*FSST2
      DO5K=3,NMODE
    5 Z3(K,J1)=SC(K)/XM(K)
      DO6K=1,2
      U3(K,J1)=0.0
      DO6 K1=3,NMODE
    6 U3(K,J1)=U3(K,J1)+Z3(K1,J1)*FE(K1,K)
      IF(LP-1)31,30,31
   30 PRINT 32,M1
   32 FORMAT(9H        M1=,I5)
      PRINT 33
   33 FORMAT(6X6HSUB XB)
      PRINT 34
   34 FORMAT(6X2HZ3)
      DO 35 K=1,NMODE
   35 PRINT 205,Z3(K,J1)
      PRINT 36
   36 FORMAT(6X2HF ,11X2HU3)
      DO37K=1,2
   37 PRINT 205,F(K,J1),U3(K,J1)
   31 GOTO200
```

```
   70 IF(F(2,J1)+F1(2))40,50,50
   40 F(1,J1)=F1(1)
      F(2,J1)=-F1(2)
      GOTO8
   50 F(1,J1)=F1(1)
      GOTO8
   60 IF(F(1,J1)+F1(1))140,80,80
  140 IF(F(2,J1)-F1(2))100,90,90
   90 F(1,J1)=-F1(1)
      F(2,J1)=F1(2)
      GOTO8
  100 IF(F(2,J1)+F1(2))101,102,102
  101 DO99K=1,2
   99 F(K,J1)=-F1(K)
      GOTO8
  102 F(1,J1)=-F1(1)
      GOTO8
   80 IF(F(2,J1)-F1(2))120,110,110
  110 F(2,J1)=F1(2)
      GOTO8
  120 IF(F(2,J1)+F1(2))130,400,400
  130 F(2,J1)=-F1(2)
      GOTO8
  400 IF(LP-1)200,403,200
  403 PRINT 401,M1
  401 FORMAT(9H        M1=,I5)
      PRINT 402
  402 FORMAT(6X4HEXIT)
  205 FORMAT(3F14.6)
  200 RETURN
      END
```

```
*****************************
*     PROGRAM NAME-PLOTXY     *
*****************************
C     THE PROGRAM PLOTXY PLOTS DISPLACEMENT,VELOCITY,ACCELERATION OF
C     THE AIRPLANE INCLUDING THOSE AT THE PILOT LOCATION
*      LABEL
*     FORTRAN
*     LIST
CPLOTXY
      DIMENSION N1(50),DT(50),MN(15),U(15,200),V(15,200),U(8),L(8),
     1YAXIS(6),NYAXIS(6),PMODE(15),MODE(15),A(3),NA(3),ALABL(13),
     2LABL(13),FE(15),VPP(200),UPP(200),T(150),K(150)
      EQUIVALENCE(NYAXIS,YAXIS),(NA,A),(MODE,PMODE),(ALABL,LABL)
  101 FORMAT(12A6)
   99 FORMAT(5F14.6)
  100 FORMAT(15I4)
  195 FORMAT(F6.1,F6.4)
C     READ IN DATA
      READ 100, L10
      L11=0
      REWIND 6
      REWIND 7
      REWIND 1
  703 READ TAPE 7,NC,NCC,JP,MP1,NT,NMODE
      READ TAPE 7,(N1(K),K=1,NT)
      READ TAPE 7,(DT(K),K=1,NT)
      PRINT 200,NC
  200 FORMAT(7H RUNWAY,I5)
      PRINT 201,NCC
  201 FORMAT(9H AIRPLANE,I5)
      PRINT 222,JP,MP1,NT,NMODE
  222 FORMAT(10I7)
      XMP1=MP1
      READ 100,K,K1,LP,LPP,LL,LG,K7
      PRINT 100,K,K1,LP,LPP,LL,LG,K7
      READ 99,(FE(NK),NK=1,NMODE)
      PRINT 99,(FE(NK),NK=1,NMODE)
      READ 99,YMAX,XSCALE
      YMIN=-YMAX
      SCALE=YMAX/5.0
      PRINT 99,YMAX,XSCALE,SCALE
      WRITE OUTPUT TAPE 1,195,SCALE,XSCALE
      REWIND 1
      READ INPUT TAPE 1,101,B(5),C(5)
      REWIND 1
      PRINT 101,B(5),C(5)
      B(1)=6H(44HSC
      B(2)=6HALE  Y
      B(3)=6H  1 IN
      B(4)=6HCH   =
      B(6)=6HINCHES
      B(7)=7H       X
      B(8)=0H
      YSC=5H/ SEC
      C(1)=6H(32HSC
      C(2)=6HALE  X
      C(3)=6H  1 IN
      C(4)=6HCH   =
      C(6)=6HSECOND
      YAXIS(1)=6HDISPLA
```

```
      YAXIS(2)=6HCEMENT
      YAXIS(3)=6HVELOCI
      YAXIS(4)=2HTY
      YAXIS(5)=6HACCELE
      YAXIS(6)=6HRATION
C     SPECIFY WHICH CURVE(OR CURVES) IS TO BE PLOTTED
      READ 101,(ALABL(I),I=2,13)
      PRINT 101,(ALABL(I),I=2,13)
      ALABL(1)=4H(74H
      DO2I=1,5,2
      IF(NYAXIS(I)-LABL(2))2,3,2
    2 CONTINUE
    3 IF(I-3)51,52,53
   52 B(7)=YSC
      GOTO51
   53 B(7)=YSC
      B(8)=YSC
   51 CONTINUE
      T=0.0
      KG=1
      KKG=0
      NG=N1(1)+1
      NKG=1
      XNKG=NKG
   63 IF(MP1-NG)61,61,62
   61 T=DT(KG)*(XMP1-XNKG)+T
      GOTO 81
   62 XN1=N1(KG)
      T=DT(KG)*XN1+T
      KG=KG+1
      KKG=KKG+1
      NG=NG+N1(KG)
      NKG=NKG+N1(KKG)
      XNKG=NKG
      GOTO 63
   81 XE=T/XSCALE
      XM=XE+4.0
      CALL GRAPH(XM,10.0,0.0)
      CALL FRAME(1.0,1.0)
      CALL YLN(0.0,10.0,4.0,0.0)
      CALL XLN(4.0,XM,5.0,1.0)
      CALL LTR(0.25,2.0,1.1,ALABL)
      CALL LTR(0.5,2.0,1.1,C)
      CALL LTR(0.75,2.0,1.1,B)
      PMODE(1)=6HMODE 1
      PMODE(2)=6HMODE 2
      PMODE(3)=6HMODE 3
      PMODE(4)=6HMODE 4
      PMODE(5)=6HMODE 5
      PMODE(6)=6HMODE 6
      PMODE(7)=6HMODE 7
      PMODE(8)=6HMODE 8
      PMODE(9)=6HMODE 9
      PMODE(10)=6HMOOE10
      PMODE(11)=6HMOOE11
      PMODE(12)=6HMOOE12
      PMODE(13)=6HMOOE13
      PMODE(14)=6HMOOE14
      PMODE(15)=6HMOOE15
```

```
      A(1)=3H(9H
      IF(K7)601,600,601
  601 DO 5 J=1,K
C     SPECIFY WHICH CURVE(OR CURVES) IS TO BE PLOTTED
      READ 101,A(2),A(3)
      PRINT 101,A(2),A(3)
      DO 6 J1=1,15
      IF(MODE(J1)-NA(2))6,7,6
    6 CONTINUE
    7 MN(J)=J1
      AJ=J
      XB=0.75+0.25*AJ
      CALL LTR(XB,3.0,1.1,A)
      CALL CURVE(J,1,0.0,0.0,XB,0.0,10.0,2)
      DO 8 J2=1,10
      AJ2=J2
      Y=6.0+(AJ2-1.0)*0.1
      CALL PLOTPT(XB,Y)
    8 CONTINUE
    5 CONTINUE
  600 KXX=1
      KX=0
      NS=MP1
      I2=JP
      T1=-DT(1)
      KY=1
      KZ=N1(1)+1
      TK(1)=0.0
   14 N2=NS
      NS=NS-I2
      IF(NS)16,16,15
   15 N2=I2
   16 IF(I-3)17,18,19
C     READ IN RESPONSE OF THE AIRPLANE FROM TAPE
   17 READ TAPE 7,((U(J,L),L=1,N2),J=1,NMODE)
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      GOTO 20
   18 READ TAPE 7,GARB
      READ TAPE 7,((U(J,L),L=1,N2),J=1,NMODE)
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      GOTO20
   19 READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,(((U(J,L),L=1,N2),J=1,NMODE)
      READ TAPE 7,(((V(J,L),L=1,N2),J=1,NMODE)
      READ TAPE 7,GARB
   20 CONTINUE
      IF(LP-1)60,64,60
C     COMPUTE DISPLACEMENT,VELOCITY  AND ACCELERATION AT PILOT LOCATION
   64 DO 300 J=1,N2
      UPP(J)=0.0
      VPP(J)=0.0
      DO 301 KM=3,NMODE
      U(KM,J)=U(KM,J)*FE(KM)
      IF(I-3)301,301,140
```

```
  140 V(KM,J)=V(KM,J)*FE(KM)
      VPP(J)=V(KM,J)+VPP(J)
  301 UPP(J)=U(KM,J)+UPP(J)
  300 CONTINUE
      IF(LL-1)60,550,60
  550 DO 551 J=1,N2
      PRINT 552,(U(KM,J),KM=3,NMODE)
  552 FORMAT(8E14.6)
  551 PRINT 552,UPP(J)
      PRINT 553
  553 FORMAT(1H1)
      IF(I-3)60,60,570
  570 DO 554 J=1,N2
      PRINT 552,(V(KM,J),KM=3,NMODE)
  554 PRINT 552,VPP(J)
      PRINT 553
C     PLOT CURVES
   60 DO 38 I1=1,K1
      I8=I1
      CALL CURVE(I8,LG,0.0,-4.0,XE,-5.0,5.0,1)
      L=MN(I1)
      DO 37 J=1,N2
      M=J+I2*KX
      IF(M-KZ)40,40,41
   41 KY=KY+1
      KZ=KZ+N1(KY)
   40 T1=DT(KY)+T1
      X=T1/XSCALE
      IF(LP-1)360,361,360
  361 IF(I1-K1)362,363,362
  362 CALL PLOTPT(X,U(L,J)/SCALE)
      IF(I-3)37,37,343
  343 IF(U(L,J)-V(L,J))342,37,342
  342 CALL PLOTPT(X,V(L,J)/SCALE)
      GOTO 37
  363 IF(LPP-1)362,365,362
  365 CALL PLOTPT(X,UPP(J)/SCALE)
      IF(I-3)37,37,344
  344 IF(UPP(J)-VPP(J))345,37,345
  345 CALL PLOTPT(X,VPP(J)/SCALE)
      GOTO 37
  360 CALL PLOTPT(X,U(L,J)/SCALE)
      IF(I-3)37,37,43
   43 IF(U(L,J)-V(L,J))42,37,42
   42 CALL PLOTPT(X,V(L,J)/SCALE)
   37 CONTINUE
      IF(I1-K1)660,38,660
  660 IF(KXX-1)652,653,652
  653 TG(KXX)=T1-TK(KXX)
      T1=T1-TG(KXX)-DT(KY)
      GOTO 38
  652 TK(KXX)=TG(KXX-1)+TK(KXX-1)
      TG(KXX)=T1-TK(KXX)
      T1=T1-TG(KXX)-DT(KY)
   38 CONTINUE
      KXX=KXX+1
      KX=KX+1
      IF(NS)30,30,29
   29 GOTO14
```

```
   30 L11=L11+1
      IF(L11-L10)700,701,700
  700 REWIND 7
      END FILE 6
      END FILE 6
      GOTO 703
  701 CALL NOPLOT
      END FILE 6
      END FILE 6
      CALL REWUNL(6)
      CALL REWUNL(7)
      CALL EXIT
      END
```

```
*****************************
*     PROGRAM NAME-PLOTF    *
*****************************
C     THE PROGRAM PLOTF PLOTS THE TIRE FORCES OF THE AIRPLANE
*     FORTRAN
*     LABEL
*     LIST
CPLOTF
      DIMENSION N1(50),DT(50),B(8),C(6),MN(2),TG(150),TK(150),FS(2),
     1FST(2,200),YAXIS(6),NYAXIS(6),PFORCE(2),MFORCE(2),A(3),NA(3),
     2ALABL(13),LABL(13)
      EQUIVALENCE(NYAXIS,YAXIS),(NA,A),(MFORCE,PFORCE),(ALABL,LABL)
  101 FORMAT(12A6)
  100 FORMAT(15I4)
   99 FORMAT(5F14.6)
      REWIND 6
      REWIND 1
      REWIND 7
C     READ IN DATA
      READ 100, L10
      L11=0
  703 READ TAPE 7,NC,NCC,JP,MP1,NT,NMODE
      READ TAPE 7,(N1(K),K=1,NT)
      READ TAPE 7,(DT(K),K=1,NT)
      PRINT 200,NC
  200 FORMAT(7H RUNWAY,I5)
      PRINT 201,NCC
  201 FORMAT(9H AIRPLANE,I5)
      PRINT 222,JP,MP1,NT,NMODE
  222 FORMAT(10I7)
      XMP1=MP1
      READ 100,K1,K,LG
      PRINT 100,K1,K,LG
      READ 99,(FS(I),I=1,2)
      PRINT 99,(FS(I),I=1,2)
      READ 99,YMAX,XSCALE
      YMIN=-YMAX
      SCALE=YMAX/5.0
      PRINT 99,YMAX,XSCALE,SCALE
      WRITE OUTPUT TAPE 1,195,SCALE,XSCALE
      REWIND 1
      READ INPUT TAPE 1,101,B(5),C(5)
      REWIND 1
  195 FORMAT(F6.0,F6.4)
      PRINT 101,B(5),C(5)
      B(1)=6H(44HSC
      B(2)=6HALE  Y
      B(3)=6H  1 IN
      B(4)=6HCH   =
      B(6)=6HPOUNDS
      B(7)=7H       X
      B(8)=0H       '
      C(1)=6H(32HSC
      C(2)=6HALE  X
      C(3)=6H  1 IN
      C(4)=6HCH   =
      C(6)=6HSECOND
      READ 101,(ALABL(I),I=2,13)
      PRINT 101,(ALABL(I),I=2,13)
      ALABL(1)=4H(74H
C     READ IN TIRE FORCE RESPONSE FROM TAPE
   16 READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,GARB
      READ TAPE 7,((FST(J,L),L=1,N2),J=1,2)
C     PLOT TIRE FORCE(OR FORCES)
      DO 38 I1=1,K1
      I8=I1
      CALL CURVE(I8,LG,0.0,-4.0,XE,-5.0,5.0,1)
      L=MN(I1)
      DO 37 J=1,N2
      M=J+12*KX
      IF(M-KZ)40,40,41
   41 KY=KY+1
      KZ=KZ+N1(KY)
   40 T1=DT(KY)+T1
      X=T1/XSCALE
      FF=FST(L,J1)-FS(L)
      CALL PLOTPT(X,FF/SCALE)
   37 CONTINUE
      IF(I1-K1)660,38,660
  660 IF(KXX-1)652,653,652
  653 TG(KXX)=T1-TK(KXX)
      T1=T1-TG(KXX)-DT(KY)
      GOTO 38
  652 TK(KXX)=TG(KXX-1)+TK(KXX-1)
      TG(KXX)=T1-TK(KXX)
      T1=T1-TG(KXX)-DT(KY)
   38 CONTINUE
      KXX=KXX+1
      KX=KX+1
      IF(NS)30,30,29
   29 GOTO14
   30 L11=L11+1
      IF(L11-L10)700,701,700
  700 REWIND 7
      END FILE 6
      END FILE 6
      GOTO 703
  701 CALL NOPLOT
      END FILE 6
      END FILE 6
      CALL REWUNL(6)
      CALL REWUNL(7)
      CALL EXIT
      END
      T=0.0
      KG=1
      KKG=0
      NG=N1(1)+1
      NKG=1
      XNKG=NKG
   63 IF(MP1-NG)61,61,62
   61 T=DT(KG)*(XMP1-XNKG)+T
      GOTO 81
   62 XN1=N1(KG)
      T=DT(KG)*XN1+T
      KG=KG+1
      KKG=KKG+1
      NG=NG+N1(KG)
      NKG=NKG+N1(KKG)
      XNKG=NKG
      GOTO 63
   81 XE=T/XSCALE
      XM=XE+4.0
      CALL GRAPH(XM,10.0,0.0)
      CALL FRAME(1.0,1.0)
      CALL YLN(0.0,10.0,4.0,0.0)
      CALL XLN(4.0,XM,5.0,1.0)
      CALL LTR(0.25,2.0,1.1,ALABL)
      CALL LTR(0.5,2.0,1.1,C)
      CALL LTR(0.75,2.0,1.1,B)
      PFORCE(1)=6HMAIN
      PFORCE(2)=6HNOSE
      A(1)=3H(9H
C     SPECIFY WHICH CURVE (OR CURVES) IS TO BE PLOTTED
      DO5 J=1,K
      READ 101,A(2),A(3)
      PRINT 101,A(2),A(3)
      DO 6 J1=1,2
      IF(MFORCE(J1)-NA(2))6,7,6
    6 CONTINUE
    7 MN(J)=J1
      AJ=J
      XB=0.75+0.25*AJ
      CALL LTR(XB,3.0,1.1,A)
      CALL CURVE(J,1.0,0.0,0.0,XB,0.0,10.0,2)
      DO 8 J2=1,10
      AJ2=J2
      Y=6.0+(AJ2-1.0)*0.1
      CALL PLOTPT(XB,Y)
    8 CONTINUE
    5 CONTINUE
      KXX=1
      KX=0
      NS=MP1
      I2=JP
      T1=-DT(1)
      KY=1
      KZ=N1(1)+1
      TK(1)=0.0
   14 N2=NS
      NS=NS-12
      IF(NS)16,16,15
   15 N2=12
```

```
*****************************
*     PROGRAM NAME-STAT     *
*****************************
C     THE PROGRAM STAT COMPUTES THE PEAK, MEAN AND MEANSQUARE OF THE
C     RESPONSE OF THE AIRPLANE
*     FORTRAN
*     LABEL
*     LIST
CSTAT
      DIMENSION A(3,12,200),B(3,200),C(2,200),AM(3,12),AME(3,12),
     1AMS(3,12),BM(3),BME(3),BMS(3),DB(3),MB(3),BMAX(3),COUNTB(3,3000),
     2CM(2),CME(2),CMS(2),DC(2),MC(2),CMAX(2),COUNTC(2,3000),FE(12),
     3N1(50),DT(50),CST(2)
C     READ IN DATA
      READ TAPE 5, NC,NCC,JP,MP1,NT,NMODE
      READ TAPE 5,(N1(I),I=1,NT)
      READ TAPE 5,(DT(I),I=1,NT)
      READ 1, LP
      READ 2,(FE(I),I=1,NMODE)
    1 FORMAT(10I10)
    2 FORMAT(5F14.6)
      XMP1=MP1
      READ 2,(CST(K),K=1,2)
      READ 2,(BMAX(K),K=1,3)
      READ 2,(CMAX(K),K=1,2)
      READ 2,(DB(K),K=1,3)
      READ 2,(DC(K),K=1,2)
      DO 101 K=1,3
  101 MB(K)=(BMAX(K)/DB(K))+1.
      DO 102 K=1,2
  102 MC(K)=(CMAX(K)/DC(K))+1.
C     INITIALIZATION
      DO 7 K=1,3
      BM(K)=0.0
      BME(K)=0.0
      BMS(K)=0.0
      DO 6 I=1,NMODE
      AM(K,I)=0.0
      AME(K,I)=0.0
    6 AMS(K,I)=0.0
      MBK=MB(K)
      DO 7 KQ=1,MBK
    7 COUNTB(K,KQ)=0.0
      DO 12 K=1,2
      CM(K)=0.0
      CME(K)=0.0
      CMS(K)=0.0
      MCK=MC(K)
      DO 12 KQ=1,MCK
   12 COUNTC(K,KQ)=0.0
C     READ IN RESPONSE OF AIRPLANE FROM TAPE
      NS=MP1
      I2=JP
   14 N2=NS
      NS=NS-I2
      IF(NS)16,16,15
   15 N2=I2
   16 READ TAPE 5,((A(1,I,J),J=1,N2),I=1,NMODE)
    ' READ TAPE 5,((A(2,I,J),J=1,N2),I=1,NMODE)
      READ TAPE 5,GARB
      READ TAPE 5,((A(3,I,J),J=1,N2),I=1,NMODE)
      READ TAPE 5,((C(K,J),J=1,N2),K=1,2)
      DO 400 K=1,2
      DO 400 J=1,N2
  400 C(K,J)=C(K,J)-CST(K)
C     COMPUTE PEAK,MEAN AND MEANSQUARE OF RESPONSE
      DO 8K=1,3
      DO 8 I=1,NMODE
      DO 8 J=1,N2
      AME(K,I)=A(K,I,J)+AME(K,I)
      AMS(K,I)=A(K,I,J)**2+AMS(K,I)
    8 AM(K,I)=MAX1F(ABSF(A(K,I,J)),AM(K,I))
      DO 9 K=1,3
      DO 9 J=1,N2
      B(K,J)=0.0
      DO 9 I=3,NMODE
    9 B(K,J)=B(K,J)+A(K,I,J)*FE(I)
      DO 10 K=1,3
      DO 10 J=1,N2
      BME(K)=BME(K)+B(K,J)
      BMS(K)=BMS(K)+B(K,J)**2
   10 BM(K)=MAX1F(ABSF(B(K,J)),BM(K))
      DO 11 K=1,2
      DO 11 J=1,N2
      CME(K)=CME(K)+C(K,J)
      CMS(K)=CMS(K)+C(K,J)**2
   11 CM(K)=MAX1F(ABSF(C(K,J)),CM(K))
      IF(LP-1)200,201,201
  200 DO 123 J=1,N2
      DO 121 K=1,3
  121 B(K,J)=B(K,J)+BMAX(K)/2.0
  123 CONTINUE
      DO 129 K=1,3
      MBK=MB(K)
      DO 129 J=1,N2
      DO 127 KQ=1,MBK
      XKQ=KQ
      IF(B(K,J)-XKQ*DB(K))128,128,127
  127 CONTINUE
  128 COUNTB(K,KQ)=COUNTB(K,KQ)+1.
  129 CONTINUE
      DO 132 K=1,2
      MCK=MC(K)
      DO 132 J=1,N2
      DO 130 KQ=1,MCK
      XKQ=KQ
      IF(C(K,J)-XKQ*DC(K))131,131,130
  130 CONTINUE
  131 COUNTC(K,KQ)=COUNTC(K,KQ)+1.
  132 CONTINUE
  201 PRINT 1,NS
      IF(NS)30,30,29
   29 GOTO 14
C     PRINT OUT RESULT OF COMPUTATION
   30 DO 31 K=1,3
      DO 31 I=1,NMODE
      AME(K,I)=AME(K,I)/XMP1
   31 AMS(K,I)=AMS(K,I)/XMP1
      DO 32 K=1,3
      BME(K)=BME(K)/XMP1
   32 BMS(K)=BMS(K)/XMP1
      DO 33 K=1,2
      CME(K)=CME(K)/XMP1
   33 CMS(K)=CMS(K)/XMP1
      IF(LP-1)202,203,203
  202 DO 50 K=1,3
      MBK=MB(K)
      XB=XMP1*DB(K)
      DO 50 KQ=1,MBK
   50 COUNTB(K,KQ)=COUNTB(K,KQ)/XB
      DO 51 K=1,2
      MCK=MC(K)
      XC=XMP1*DC(K)
      DO 51 KQ=1,MCK
   51 COUNTC(K,KQ)=COUNTC(K,KQ)/XC
  203 PRINT 35
   35 FORMAT(3X2HAM)
      DO 36 K=1,3
   36 PRINT 37,(AM(K,I),I=1,NMODE)
   37 FORMAT(10E11.4)
      PRINT 38
   38 FORMAT(3X3HAME)
      DO 39 K=1,3
   39 PRINT 37,(AME(K,I),I=1,NMODE)
      PRINT 40
   40 FORMAT(3X3HAMS)
      DO 41 K=1,3
   41 PRINT 37,(AMS(K,I),I=1,NMODE)
      PRINT 42
   42 FORMAT(3X2HBM)
      PRINT 37,(BM(K),K=1,3)
      PRINT 43
   43 FORMAT(3X3HBME)
      PRINT 37,(BME(K),K=1,3)
      PRINT 44
   44 FORMAT(3X3HBMS)
      PRINT 37,(BMS(K),K=1,3)
      PRINT 45
   45 FORMAT(3X2HCM)
      PRINT 37,(CM(K),K=1,2)
      PRINT 46
   46 FORMAT(3X3HCME)
      PRINT 37,(CME(K),K=1,2)
      PRINT 47
   47 FORMAT(3X3HCMS)
      PRINT 37,(CMS(K),K=1,2)
      CALL REWUNL(5)
      IF(LP-1)204,205,205
  204 PRINT 60
   60 FORMAT(3X6HCOUNTB)
      DO 61 K=1,3
      MBK=MB(K)
      PRINT 63
   61 PRINT 62,(COUNTB(K,KQ),KQ=1,MBK)
   62 FORMAT(8E14.6)
   63 FORMAT(1H1)
      PRINT 64
   64 FORMAT(3X6HCOUNTC)
      DO 65 K=1,2
      MCK=MC(K)
      PRINT 63
   65 PRINT 62,(COUNTC(K,KQ),KQ=1,MCK)
  205 CALL EXIT
      END
```

APPENDIX 2

Airplane Data

A. Boeing 707

1. General Arrangement - see Fig. 4.

2. Inertia Data

Gross Weight of Airplane $W = 324030.0$ lbs

Unsprung Mass

Main $W_1 = 4992.0$ lbs

Nose $W_2 = 342.0$ lbs.

Airplane Pitch Moment of Inertia about C.G. $J = 0.645 \times 10^8$ lb-in-s^2

3. Modal Frequencies and Generalized Masses

Mode No.	Modal Frequencies rd/s	Generalized Masses lb-in-s^2
1	7.22	30.780
2	18.00	23.199
3	23.85	58.436
4	31.0	52.987
5	38.8	61.878
6	55.0	16.038

4. Damping Coefficient of Airframe $\lambda = 0.025$

5. Mode Shapes

Mode No.	Location on Fuselage		
	Main Gear	Nose Gear	Pilot's Compartment
1	-0.122	0.030	0.056
2	0.037	0.089	0.103
3	-0.010	0.298	0.383
4	0.230	-0.560	-0.800
5	-0.168	0.040	0.080
6	-0.065	0.083	0.160

6. Landing Gear Data

a) Tire Stiffness

Main $k_{t1} = 96500.0$ lbs/in.

Nose $k_{t2} = 13500.0$ lbs/in.

b) Limiting Coulomb Friction Force — Main $F_1' = 1000.0$ lbs.; Nose $F_2' = 600.0$ lbs.

c) Nonlinear Spring Forces - see Fig. 5.

d) Oleo Damping Coefficients - see Fig. 6.

B. Boeing 733-94

1. General Arrangement - see Fig. 7

2. Inertia Data

Gross Weight of Airplane $W = 389000.0$ lbs.

Unsprung Mass — Main $W_1 = 4650.0$ lbs.; Nose $W_2 = 460.0$ lbs.

Airplane Pitching Moment of Inertia about C.G. $J = 0.23 \times 10^9$ lb-in-s^2

3. Modal Frequencies and Generalized Masses

Mode No.	Modal Frequencies rd/s	Generalized Masses lb-in-s^2
1	11.90	41.15
2	13.11	30 60
3	23.93	28.17
4	28.37	42.75
5	33.13	28.86
6	36.51	31.95

4. Damping Coefficient of Airframe $\lambda = 0.025$

5. Mode Shapes

Mode No.	Location on Fuselage		
	Main Gear	Nose Gear	Pilot's Compartment
1	-0.130	0.122	0.204
2	-0.088	0.485	0.760
3	-0.008	0.043	0.100
4	0.020	0.278	0.651
5	0.039	0.110	0.330
6	0.162	0.089	0.284

6. Landing Gear Data

a) Tire Stiffness	Main	K_{t1} = 96000.0 lbs/in.
	Nose	K_{t2} = 9600.0 lbs/in.
b) Limiting Coulomb Friction Force	Main	F_1' = 1000.0 lbs.
	Nose	F_2' = 600.0 lbs.

c) Nonlinear Spring Force - see Fig. 8.

d) Oleo Damping Coefficient	Main	D_1 = 50.0 lb/(in/s)^2
	Nose	D_2 = 4.0 lb/(in/s)^2

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